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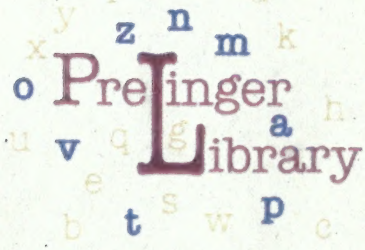

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CONTENTS

TECHNICAL BULLETIN NO. 226.—THE DISTRIBUTION AND THE MECHANICAL PROPERTIES OF ALASKA WOODS (L. J. Markwardt): Page

Purpose 1
Timber resources of Alaska 1
National-forest policy 2
Forest types 2
Coastal forests 2
Interior forests 4
Timber production, export, and yield 5
Description of species 5
Alaska white birch 7
Alaska cedar 8
Western red cedar 10
Northern black cottonwood 12
Mountain hemlock 14
Western hemlock 15
Balsam poplar 17
Sitka spruce 18
White spruce 20
Studies of mechanical properties 22
Nature of studies 22
Standard tests of small, clear specimens 22
Precautions to be observed in the use of data 40
Variation in strength of wood 41
General discussion and deductions 43
Tests of full-sized sawed structural timbers of Sitka spruce and western hemlock 45
Tests of full-sized round mine timbers of Alaska birch, western hemlock, Sitka spruce, and white spruce 49
Summary 54
Appendix 55
Detailed results of structural timber tests 55
Glossary of terms used 73
Working stresses 75
Literature cited 78

TECHNICAL BULLETIN NO. 227.—DEVELOPMENTAL STAGES OF SOME NEMATODES OF THE SPIRUROIDEA PARASITIC IN POULTRY AND GAME BIRDS (Eloise B. Cram):

Review of preceding investigations 1
Methods used in the present investigation 2
Tetrameres americana Cram, 1927 (5)[3] 3
Development in intermediate host 3
Development in final host 4
Rate of development 5
Cheilospirura hamulosa (Diesing, 1851) Diesing, 1861 (8) 8
Development in intermediate host 8
Development in final host 9
Description of adult parasite 12
Cheilospirura spinosa Cram, 1927 13
Development in intermediate host 14
Development in final host 15
Dispharynx spiralis (Molin, 1858) Skrjabin, 1916 (16) 18
Development in intermediate host 19
Development in final host 20
Seurocyrnea colini (Cram, 1927) Cram, 1930 21
Development in intermediate host 22
Development in final host 23
Summary 24
Literature cited 26

TECHNICAL BULLETIN No. 228.—CHARACTER OF THE COLLOIDAL MATERIALS IN THE PROFILES OF CERTAIN MAJOR SOIL GROUPS (M. S. Anderson and Horace G. Byers):

	Page
Introduction	1
Previous work	2
Description of soil samples	3
Mechanical and chemical composition of soils	5
Methods of study of colloidal materials	7
Character of pedocal colloids	9
Character of podsol colloids	11
Character of laterite and lateritic colloids	16
Comparison of colloids from different soil groups	19
pH values of electrodialyzed colloids	20
Summary	22
Literature cited	23

TECHNICAL BULLETIN No. 229.—VARIATIONS OF THE COLLOIDAL MATERIAL EXTRACTED FROM THE SOILS OF THE MIAMI, CHESTER, AND CECIL SERIES (R. S. Holmes and Glen Edgington):

Introduction	1
Methods	2
Description of samples	4
The Miami soils	5
The Chester soils	7
The Cecil soils	8
Composition and properties of the colloidal material isolated from soils of three series	10
General relations between the profiles	15
The mean variations	17
Differences in composition of colloids from soils of the different series	19
Summary	22
Literature cited	22

TECHNICAL BULLETIN No. 230.—MACROCENTRUS GIFUENSIS ASHMEAD, A POLYEMBRYONIC BRACONID PARASITE IN THE EUROPEAN CORN BORER (H. L. Parker):

Discovery in Europe and identity of the species	1
Geographic distribution and host relations	2
History of polyembryony in Hymenoptera	2
Technic followed	6
Explanation of symbols used in the illustrations	7
Description of *Macrocentrus gifuensis*	8
The adult	8
The egg	9
The larva	9
The prepupa and pupa	23
The cocoon	23
Biology	24
Emergence	24
Light reactions	24
Feeding	24
Oogenesis	24
Copulation	24
Oviposition	25
Segmentation of the egg	29
Growth and development of the egg	30
Pseudogerms	36
Cyst formation	38
Larval habits	38
Effect of parasite on host larva	42
Spinning and pupation	43
Average size of colony and proportion of sexes	44
Parthenogenesis	46
Consideration of the zones in which *Macrocentrus gifuensis* occurs	47
Physical characteristics	47
Climatic characteristics	48

TECHNICAL BULLETIN NO. 230.—MACROCENTRUS GIFUENSIS ASHMEAD, A POLYEMBRYONIC BRACONID PARASITE IN THE EUROPEAN CORN BORER—Continued.

Page

Seasonal history 49
Seasonal history of the host 49
Seasonal history of the parasite 49
Experimental data 51
Laboratory breeding experiments 52
Mortality in rearing of field material 52
Summary of duration of various stages 53
Rapidity of spring development 53
Mortality in the prepupal and pupal stages 55
Cold storage of overwintering host larvae containing parasites 55
Cold storage of cocoons 56
Macrocentrus gifuensis as a controlling factor of *Pyrausta nubilalis* 56
Limiting factors 57
Recommendations 57
Summary 58
Literature cited 61

TECHNICAL BULLETIN NO. 231.—A REVISION OF THE AMERICAN SPECIES OF EMPOASCA KNOWN TO OCCUR NORTH OF MEXICO (Dwight M. DeLong):

Introduction 1
The economic problem and its relation to taxonomy 2
Geographical distribution 5
Historical résumé 6
The genus and its position 7
External structural characters 8
Characters used in classification 9
The vertex 9
The last segment of the female 9
Male structures 9
Male genital pieces 10
Technic and method of study 12
Classification of the species of Empoasca 14
Key to the subgenera of Empoasca 14
The subgenus Kybos Fieber 14
The subgenus Hebata nov 32
The subgenus Empoasca Walsh 36
The subgenus Idona nov 50
List of described species with synonyms 57
Species not included in this revision 58
Literature cited 58

TECHNICAL BULLETIN NO. 232.—A LABORATORY STUDY OF THE FIELD PERCOLATION RATES OF SOILS (C. S. Slater and H. G. Byers):

Introduction 1
Review of the literature 2
Soil description and location 3
The soil core auger 3
Core preparation and percolation apparatus 6
Evaluation of experimental data 8
Preparation and the percolation rates of laboratory-packed soil tubes 12
Preparation of the soil samples 12
The soil tubes 12
Filling the soil tubes 13
Presaturation of the sample 13
A consideration of the experimental data from the cores and from the laboratory-packed samples 14
The correlation of percolation data with other soil properties 17
The properties studied 17
Properties which correlate with permeability 19
Erosion and soil permeability 21
Summary 22
Literature cited 23

TECHNICAL BULLETIN NO. 233.—APANTELES THOMPSONI LYLE, A BRACONID PARASITE OF THE EUROPEAN CORN BORER (Arlo M. Vance): Page

Introduction 1
Distribution and host relations 2
Climate and agriculture of favored habitat 3
Economic importance of *Apanteles thompsoni* 3
Descriptions 4
Adult 4
Egg 5
First-stage larva 6
Second-stage larva 8
Last-stage larva 8
Pupa 12
Cocoon 12
Biology 12
Behavior under laboratory conditions 12
Oviposition 13
Development of the egg 14
Discussion of the embryonic envelope 15
Larval growth and pupation 18
Life of the adult 19
Effect of parasite on host 19
Seasonal history 20
Limiting factors 21
Thelyotoky 22
Economic importance of thelyotoky in the hymenopterous parasites 23
Methods of quantity collection and shipment 24
Summary 25
Literature cited 26

TECHNICAL BULLETIN NO. 234.—MARKETING APPLES GROWN IN THE CUMBERLAND-SHENANDOAH REGION OF PENNSYLVANIA, VIRGINIA, AND WEST VIRGINIA (Carl R. Swinson, J. J. Vernon, F. L. Lininger, F. P. Weaver, and A. J. Dadisman):

Introduction 1
Method of study and application of results 3
Market outlets 5
Where the apples go 6
Prices received at destination 7
Wholesale and retail outlets in Pennsylvania cities 12
Wholesale and retail outlets in Virginia and West Virginia cities 17
Heavy supplies add to marketing difficulties 20
Market supplies of some varieties to increase 23
Cold storage an aid to orderly marketing 26
Some varieties sell better than others 29
Prices differ in various parts of region 30
Prices of varieties influenced by time of sale 32
Varieties handled in local markets 34
Grade an important price factor 37
Marketing services and charges 40
Methods of sale 46
Containers 48
Summary 50

TECHNICAL BULLETIN NO. 235.—QUALITY OF ALFALFA HAY IN RELATION TO CURING PRACTICE (T. A. Kiesselbach and Arthur Anderson):

Introduction 1
Review of literature 2
Experimental work 3
Plan of curing tests 3
Determinations of initial basic leafiness and protein 7
Immediate raking compared with partial swath curing 8
Effect of overcuring in swath 9
Effect of size of windrow 9
Effect of turning windrow when partially cured 11
Relation of direction of windrow to curing 11
Direction of raking in relation to mower swath 12

TECHNICAL BULLETIN No. 235.—QUALITY OF ALFALFA HAY IN RELATION TO CURING PRACTICE—Continued.
Experimental work—Continued. Page
Effect of type of rake 13
Time of cutting during day in relation to curing 13
Relation of cock curing to hay quality 14
Effect of turning hay exposed to external moisture 15
Effect of rain on protein content 16
Effect of artificial drying 16
Relation of leafiness of cured hay to protein content 17
Progressive loss of water from alfalfa in relation to curing practice 18
How moisture is lost from stems in curing 20
Discussion and conclusions 22
Literature cited 25

TECHNICAL BULLETIN No. 236.—THE TIME TO HARVEST FIBER FLAX (Brittain B. Robinson):
Introduction 1
Review of literature 2
Experimental methods 4
Yield of seed 8
Germination of seed 10
Yield of straw 15
Yield of fiber 15
Quality of fiber 16
Discussion 18
Summary 21
Literature cited 21

TECHNICAL BULLETIN No. 237.—ECONOMIC FACTORS AFFECTING THE BEEF-CATTLE INDUSTRY OF VIRGINIA (Charles A. Burmeister, Herman M. Conway, and Albert P. Brodell):
Introduction 1
Importance of grass in the economic program of Virginia cattle producers 2
Early development of the beef-cattle industry in Virginia 3
Rise and decline of United States export trade in cattle and beef 3
Changes in the beef-cattle industry of the United States 4
Distribution of beef cattle in Virginia 6
Method of finishing steers 7
Southwest Virginia 7
Shenandoah Valley and north Virginia 9
Methods of selling cattle 9
Buying for future delivery, or contract buying 10
Furnishing stockers and feeders on contract 11
Price determination under the contract system 11
Disadvantages of the contract system 12
Market outlets 13
Richmond 14
Baltimore 14
Lancaster 14
Jersey City 16
Transportation service as a factor in market selection 17
Market destination of cattle from southwest Virginia 19
Seasonal movements of Virginia cattle 20
Production records of selected shipments of Virginia cattle 23
Description of farms studied 24
Crop production and marketing conditions, 1923 and 1924 27
Methods of compiling costs and limitations of cost data 27
Results of different methods of wintering and fattening steers 29
Marketing records of steers from selected droves 34
Slaughter information regarding cattle followed to market 38
Marketing costs of competing cattle 41
Comparison of cattle prices at Jersey City and Chicago 43
Market grades of cattle 44
Competition for Virginia beef in the New York market 47

TECHNICAL BULLETIN NO. 237.—ECONOMIC FACTORS AFFECTING THE BEEF-CATTLE INDUSTRY OF VIRGINIA—Continued. Page

Problem of dark-colored beef 51
Trade opinion regarding Virginia cattle 52
Possibilities of increasing returns on Virginia steers by improving the grade 54
Conclusions and recommendations 57
Summary 60

TECHNICAL BULLETIN NO. 238.—THE PHARMACOLOGY OF THALLIUM AND ITS USE IN RODENT CONTROL (James C. Munch and James Silver):

Introduction 1
Review of the literature on thallium 2
Occurrence and properties 2
Determination 3
Action of thallium on bacteria 4
Action of thallium salts on animals 4
Action of thallium salts on man 8
Medicinal uses 10
Antidotes for thallium poisoning 12
Laboratory experiments 12
Method adopted for feeding experiments 12
Feeding experiments 13
Physiological action on rats 18
Toxicity of thallium to rabbits by intravenous injection 18
Summary 19
Literature 19
Laboratory experiments with rodents 20
Conclusions 20
Bibliography 21

TECHNICAL BULLETIN NO. 239.—A METHOD OF DETERMINING THE VOLUME AND TONNAGE OF HAYSTACKS (W. H. Hosterman):

Stack hay sales important but methods inaccurate 1
Reasons why hay is sold by measure 2
Popular measurement rules not based on research 2
Review of previous research 3
Cooperative investigations on stack measurements, 1927, 1928, and 1929 6
Objectives 6
Scope of work 7
Data collected 8
Problems presented for study 11
Volume of rectangular stacks 12
Studies on area of cross sections 12
Studies of cross-section areas by old rules 13
Formulation of new rules for determining cross-section area 16
Volume of round stacks 20
Studies on the determination of volume 20
Studies of the accuracy of old volume rules for round stacks 21
Formulation of new rule for determining volume of round stacks 24
Determination of cubic feet required for a ton 28
Stacks of various kinds segregated 28
Method of determining volume per ton 28
Cubic feet per ton 29
Variations in density 32
Need for additional research 34
Summary 35

TECHNICAL BULLETIN NO. 240.—THE CHEMICAL ERADICATION OF RIBES (H. R. Offord):

Introduction 1
Discussion of early work 3
Tests of chemicals 5
Preliminary tests 5
Repeated application to resistant Ribes 9
Application to soil surface about the base of plants 10

TECHNICAL BULLETIN NO. 240.—THE CHEMICAL ERADICATION OF RIBES—Continued. Page

Sodium-chlorate sprays 12
Large-scale tests 12
Relative susceptibility of Ribes 13
Observations on killing effect 13
Factors influencing effective application 18
Inflammability 18
Field equipment and methods of spraying chemicals 19
Summary 22
Literature cited 24

TECHNICAL BULLETIN NO. 241.—ANALYSES AND COMPOSITION OF CALIFORNIA LEMON AND ORANGE OILS (H. D. Poore):

Introduction 1
Analyses of California lemon and orange oils 3
Methods of analyses 3
Discussion of results 10
Effect of temperature, air, and light on limonene and the citrus oils 11
Composition of California lemon and orange oils 12
Lemon oil 12
Orange oil 22
Summary 28
Literature cited 29

TECHNICAL BULLETIN NO. 242.—BIOLOGY OF THE INDIAN-MEAL MOTH ON DRIED FRUITS IN CALIFORNIA (J. C. Hamlin, W. D. Reed, and M. E. Phillips):

Introduction 1
History and distribution 2
Description of stages of the Indian-meal moth 2
The egg 2
The larva 2
The pupa 3
The adult 3
Food habits 3
Nature of damage 4
Plan of biological studies 4
Rearing methods 5
Seasonal history 6
Pupation of the overwintered larvae 7
Emergence of spring adults 8
Life-history studies 9
The adult 9
The egg 13
The larva 15
The pupa 18
Length of life cycle 19
Number of generations per year 22
Parasites 23
Summary 24
Literature cited 26

TECHNICAL BULLETIN NO. 243.—TRANSPORTING AND HANDLING MILK IN TANKS (Ralph P. Hotis):

Rapid increase in tank hauling 1
Causes of changes in methods of hauling 1
Object of study 2
Tanks mounted on motor trucks 2
Kinds in use, capacity, and costs 2
Length of routes and speed of hauling 3
Need for supplemental tanks 5
Temperature changes of milk in motor tanks 6
Handling milk from motor tanks at city plants 7
Costs of hauling by tank truck 14
Conditions under which tank-truck hauling is unsatisfactory 16

TECHNICAL BULLETIN NO. 243.—TRANSPORTING AND HANDLING MILK IN TANKS—Continued. Page

Tank cars 16
Equipment 16
Length of routes and number of cars required 17
Need for supplemental tanks 18
Handling milk from tank cars at city plants 18
Conditions under which tank-car hauling is unsatisfactory 22
Advantages of hauling milk in tanks as compared with hauling milk in cans 23

TECHNICAL BULLETIN NO. 244.—HARVESTING SMALL GRAIN, SOYBEANS, AND CLOVER IN THE CORN BELT WITH COMBINES AND BINDERS (L. A. Reynoldson, W. R. Humphries, and J. H. Martin):

Introduction 1
Purpose and extent of study 2
Description of area and type of farming 2
Harvesting equipment 4
Power and labor 7
Methods of harvesting the crops 8
Comparison of harvesting and threshing methods 12
Crops and acres harvested 12
Days on which harvesting was done 14
Rate of harvesting 14
Condition of crop at harvest time 20
Reliability of combines and binders 21
Harvesting and threshing losses 21
Straw saving 24
Costs of harvesting and threshing 24
Labor 25
Power 29
Fuel and lubricants 30
Threshing 32
Repairs 32
Shelter 33
First cost and depreciation 34
Costs for different acreages harvested 35
Acreages on which combines and binders will be economical 39
The harvest season 40
Rainfall 41
Weather conditions 44
Quality and condition of grain 44
Grain handling and storing 47
Cooperative ownership 49
Custom work 50
Summary 52

TECHNICAL BULLETIN NO. 245.—ARSENICAL AND OTHER FRUIT INJURIES OF APPLES RESULTING FROM WASHING OPERATIONS (D. F. Fisher and E. L. Reeves):

Introduction 1
Arsenical injury 2
Occurrence in the orchard 2
Occurrence on stored apples 3
Methods of prevention 7
Hydrochloric-acid injury 8
Injury from alkaline solvents 9
Injury at the core 9
Heat injury 9
Influence of washing on storage rots 10
Conclusion 11
Summary 11
Literature cited 12

TECHNICAL BULLETIN NO. 246.—THE RELATION OF SEASON OF WOUNDING AND SHELLACKING TO CALLUS FORMATION IN TREE WOUNDS (Rush P. Marshall):

	Page
Introduction	1
Review of literature	2
Experimental methods and procedure	3
Reasons for testing shellac	6
Results expressed in diagrams of callus growth	8
Results expressed as average area of callus growth	15
Discussion of results	18
Effect of season of wounding as shown by area of callus	18
Effect of season of wounding as shown by shape of callus	19
Effect of shellac as shown by area of callus	19
Effect of shellac as shown by shape of callus	22
Effect of vigor on healing	25
Fungus growth on the wounds	25
Application of results	26
Summary	27
Literature cited	28

TECHNICAL BULLETIN NO. 247.—FOREST TYPES IN THE SOUTHWEST AS DETERMINED BY CLIMATE AND SOIL (G. A. Pearson):

Introduction	1
The forest types or zones and other vegetational zones of Arizona and New Mexico	3
Woodland	5
Western yellow pine zone	7
Douglas fir zone	9
Engelmann spruce zone	12
Climate	15
Sources of data	15
The growing season	19
Temperatures	21
Precipitation	48
Wind, humidity, and evaporation	58
Soil moisture	63
Soils	72
Geologic origin	72
Chemical composition	73
Physical characteristics	75
Soil zones as related to climate	80
Description of the soil zones	82
Résumé of findings on climate and soil	85
Characteristics of the species	86
Relative heat requirements	86
Relative light requirements	89
Relative moisture requirements	93
Growth periods	99
Frequency of seed crops	100
Rate of growth	101
Correlation between physical conditions and the distribution of species	105
Planting experiments	105
Natural occurrence an indication of requirements	114
Temperature and moisture as limiting factors in natural distribution	115
Range of temperature and moisture within each forest zone in the Southwest	119
Specific requirements of species	123
Temperature and moisture requirements	123
Soil requirements	125
Application of data on forest types to forestry practice	125
Need for further study	125
Measurement of site factors	126
Possibilities in the use of plant indicators	127
A scientific basis for silviculture	128
Summary	131

TECHNICAL BULLETIN NO. 247.—FOREST TYPES IN THE SOUTHWEST AS DETERMINED BY CLIMATE AND SOIL—Continued. Page
Appendix 134
Methods of study employed in compiling the San Francisco Mountains records 134
Description of climatological stations employed in the San Francisco Mountains study 137
Literature cited 141

TECHNICAL BULLETIN NO. 248.—WOOD-LIQUID RELATIONS (L. F. Hawley):
Introduction 1
The structure of wood 3
Softwoods 3
Hardwoods 4
Dimensions of wood elements 5
Statics 5
Absorption in general 6
Absorption of water 6
Absorption of liquids other than water 14
Dynamics 15
Impregnation by pressure 15
Diffusion caused by differences in moisture content 22
Movement of liquid above the fiber-saturation point 24
Conclusions 31
Summary 32
Literature cited 32

TECHNICAL BULLETIN NO. 249.—SOME FACTORS AFFECTING THE VISCOSITY OF CREAM (C. J. Babcock):
Introduction 1
Method used for measuring viscosity 2
Method used for microscopic studies 2
Factors affecting viscosity 3
Effect of butterfat content and temperature 3
Effect of age upon viscosity 4
Effect of pasteurizing temperature 6
Gravity-separated cream and centrifugally separated cream compared 7
Effect of standardization 8
Effect of freezing 9
Effect of acidity 9
Effect of cooling 10
Effect of separating temperature 11
Effect of storage of milk 12
Effect of pasteurizing before separating 12
Effect of homogenization 13
Effect of homogenizing temperature 14
Effect of rehomogenization 16
Effect of solids not fat 16
Conclusions 18
Literature cited 18

TECHNICAL BULLETIN NO. 250.—TIMBER GROWING AND LOGGING PRACTICE IN THE SOUTHERN APPALACHIAN REGION (E. H. Frothingham):
Introduction 1
The timber-supply problem in the southern Appalachians 5
Distribution and condition of timberland 6
Timber growing for industrial needs 7
Development of the lumber industry 8
Utilization of small timber 10
Need for continuous production 14
Timber growing and the problem of land use 17
Factors that affect continuous timber production 20
Composition of the forest 21
Mountain forests 21
Plateau and valley forests 22

TECHNICAL BULLETIN NO. 250.—TIMBER GROWING AND LOGGING PRACTICE IN THE SOUTHERN APPALACHIAN REGION—Continued.

Page

Factors that affect continuous timber production—Continued.
- Relative value of the species — 25
- The yield of the forest — 30
  - Yield of the old-growth forest — 30
  - Yield of repeatedly culled forest — 31
  - Yield of second growth — 35
- Forest-fire damage — 37
- Establishment and early development of stands — 40
  - On unburned cut-over lands — 40
  - After fires on cut-over lands — 41
  - Seedling and sprout reproduction — 43
- Effect of competition in young stands — 45
- Forest-insect damage — 47
  - Insects affecting living trees — 47
  - Insects affecting forest products — 49
- The chestnut blight — 49
- Economy in reserving small trees for growth — 54

Measures necessary to keep forest lands productive — 57
- Fire prevention — 57
  - Causes of fires — 57
  - Need for cooperation — 58
  - General measures — 59
  - Special measures — 63
- Logging practice — 66
  - Improvement of poor stand conditions — 66
  - Selection of seed trees — 69

Management of forests to produce full timber crops — 70
- Full-crop management for large timber tracts below the spruce zone — 71
  - Methods of cutting — 71
  - Improvement cutting and girdling — 73
  - Weeding — 74
  - Thinning — 75
  - Slash disposal — 75
- Spruce-forest management for full crops — 75
- Management of farm woods — 78
  - Old-growth stands — 79
  - Second-growth stands — 80
  - Species to be favored — 80
  - Control of grazing — 81
  - Cooperative marketing — 81

Summary of recommendations for handling forest lands — 82
- To keep forest lands productive — 82
  - Fire prevention — 82
  - Insect control — 83
  - Logging practice — 84
- To produce full timber crops — 85
  - Large timber tracts — 85
  - Spruce forest — 85
  - Farm woods — 85

Public action needed for better development of timberlands — 86

Appendix — 87
- Sources of technical advice and service for private forest management — 87
- Common and scientific names of trees referred to in text — 87

Literature cited — 89

○

TECHNICAL BULLETIN No. 226 FEBRUARY, 1931

THE DISTRIBUTION AND THE MECHANICAL PROPERTIES OF ALASKA WOODS

BY

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Senior Engineer, Forest Products Laboratory
Branch of Research, Forest Service

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE DISTRIBUTION AND THE MECHANICAL PROPERTIES OF ALASKA WOODS

By L. J. MARKWARDT,[1] *Senior Engineer, Forest Products Laboratory,*[2] *Branch of Research, Forest Service*

CONTENTS

	Page
Purpose	1
Timber resources of Alaska	1
National-forest policy	2
Forest types	2
Coastal forests	2
Interior forests	4
Timber production, export, and yield	5
Description of species	5
Alaska white birch	7
Alaska cedar	8
Western red cedar	10
Northern black cottonwood	12
Mountain hemlock	14
Western hemlock	15
Balsam poplar	17
Sitka spruce	18
White spruce	20
Studies of mechanical properties	22
Nature of studies	22
Standard tests of small, clear specimens	22
Studies of mechanical properties—Continued.	
Precautions to be observed in the use of data	40
Variation in strength of wood	41
General discussion and deductions	43
Tests of full-sized sawed structural timbers of Sitka spruce and western hemlock	45
Tests of full-sized round mine timbers of Alaska birch, western hemlock, Sitka spruce, and white spruce	49
Summary	54
Appendix:	
Detailed results of structural timber tests	55
Glossary of terms used	73
Working stresses	75
Literature cited	78

PURPOSE

Accurate data on the distribution and mechanical properties are invaluable when a wood suitable for a specific purpose is to be selected. This bulletin provides reliable data on the principal commercial woods of Alaska for architects, engineers, contractors, woodworkers, and others who require detailed information regarding Alaska woods and a means of comparing their respective properties.

TIMBER RESOURCES OF ALASKA

Of Alaska's total forested area, conservatively estimated at over 70,000,000 acres, two national forests comprise 21,347,000 acres, di-

[1] Acknowledgment is made to C. H. Flory, B. F. Heintzleman, H. E. Smith, W. J. McDonald, and L. C. Pratt of the U. S. Forest Service in Alaska, for their cooperation in this work, particularly in the procurement of test material.

[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

vided as follows: Tongass National Forest, 16,547,000; Chugach National Forest, 4,800,000.

The Chugach and Tongass National Forests are under the administration of the Forest Service, United States Department of Agriculture, in much the same manner as the national forests in the States. Most national-forest business is handled locally by resident officers. The chief administrative officer is the regional forester, with headquarters at Juneau.

The remaining forest-covered land, largely the interior forest, is on the unreserved public domain under the administration of the General Land Office, United States Department of the Interior. Probably not over 5,000 acres are private forest lands (*24*).[3]

NATIONAL-FOREST POLICY

The management policy for the Alaska national forests has as its objective the providing of a continuous and adequate supply of timber for the present and future wood-using industries of the region. It is hoped that such industries will in turn foster the permanent development of the Territory, and permit a sustained contribution to the Nation's supply of timber products. The objective, of course, includes the furnishing of a permanent and convenient supply of timber for local consumption.

Of the two national forests, the Tongass shows the most immediate promise of active development. It has, after examination and careful study, been divided into pulp-timber allotments, local-use allotments, and general-use areas.

Timber sales are made with the understanding that the wood is to be used for primary manufacture within the Territory and is not to be exported in the form of logs, cordwood, or other raw products, except in individual cases to permit more complete utilization.

FOREST TYPES

The Alaska forests are of two distinct kinds; the coastal forests and the interior forests. (Fig. 1.) Because of its higher density of stand and its accessibility, the coastal type, as found in the national forests, is of the greater commercial importance, and is the principal source of material under consideration in this bulletin.

COASTAL FORESTS

TONGASS NATIONAL FOREST

The coastal forests of southern Alaska, to as far north as Cook Inlet, are of luxuriant growth and may be regarded as an extension of the forests occurring in the Pacific Northwest. The Alaska forests reach their best development in the islands and in the narrow strip of mainland extending for a distance of about 400 miles along the west side of British Columbia. (Pl. 1.) The forest floor in this region, strewn with quantities of decaying down timber, is generally covered with a heavy layer of moss, often 6 inches or more in thickness. The ground surface is rough, for the top soil, though rich, is relatively shallow and bedrock is exposed in many places.

[3] Italic numbers in parentheses refer to Literature Citey, p. 78.

Heintzleman (*10, p. 7–8*) described the forests in part, as follows:

As found in southeastern Alaska, the coast forest is predominantly a mixed stand of western hemlock and Sitka spruce. [Pl. 2.] In many places western red cedar and Alaska cedar are associated with the predominant species in small proportions. Any one of these four species may be found occasionally in a pure stand of small extent. The forests have an almost tropical density of trees and underbrush. In the usual mixed stand hemlock with some cedar forms a dense main cover, and this is overtopped by the more light-demanding spruce, which occurs singly or in small groups. Small bushy saplings of the shade-resistant hemlock and cedars, various species of blueberry (Vaccinium), and devil-club (*Echinopanax horrida*), and other shrubs form a dense understory. * * * [Pl. 3, A.]

The stands of timber are even-aged; many age classes are represented in the forest as a whole; and the stands of the older age classes are greatly in the majority, perhaps three-fourths of the commercial timber of the region being mature and overmature. The even-aged stands are characteristic of

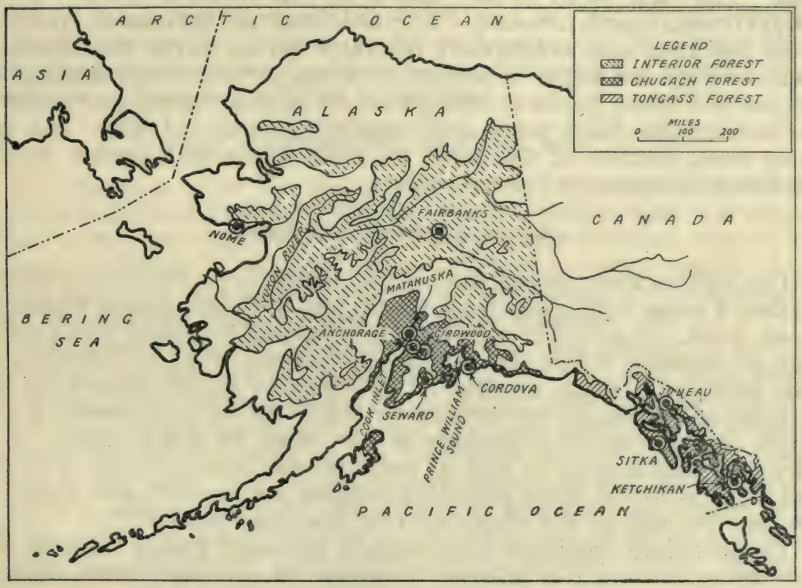


FIGURE 1.—Location of the forests of Alaska

western hemlock and Sitka spruce; the great number of age classes and the preponderance of old timber are to be expected in an extensive virgin forest.

The average stand per acre for the commercial forests as a whole is about 25,000 board feet, but the individual logging units vary widely from this average. A volume of 30,000 to 40,000 board feet per acre is common on many extensive areas, and 50,000 board feet or more per acre frequently occurs on small units. The majority of the merchantable trees are from 2 to 4 feet in diameter and from 90 to 140 feet in height.

The forest cover extends from the edge of tidewater [Pl. 3, C] to an altitudinal limit of about 2,750 feet in the southern part of the region and 2,000 feet in the northern sections. At an elevation of about 1,500 feet the commercial timber gives way to stands of dwarfed, limby trees, which are designated "subalpine" and classified as noncommercial. Because of the prevailing steep slopes the commercial forests form relatively narrow bands along the shore lines of the mainland and islands, rarely extending inland more than 5 miles, except along the valleys of the few large streams.

It is estimated that 75 per cent of the commercial timber of the Tongass National Forest lies within 2½ miles of tidewater.

The forests of commercial value are broken into large blocks by frequent extensive noncommercial areas of "scrub," as the open stands of somewhat dwarfed timber are called, and by muskegs of peat which carry only isolated small trees.

Trees with dead spike tops are a conspicuous feature of the noncommercial scrub areas and of the cedar areas. Spike-topped individuals, so decadent as to be classed as unmerchantable, are fairly prevalent also in the overmature hemlock-spruce stands, but their effect in depreciating the value of these stands is likely to be overestimated. They form a relatively small percentage of the timber, which as a whole is of good quality. Only a few spike tops occur in the extensive hemlock-spruce area of mature timber and of piling-size young timber.

Commercial timber of the principal species in the Tongass National Forest is conservatively estimated to occur by volume in the following amounts: Western hemlock, 74 per cent; Sitka spruce, 20 per cent; western red cedar, 3 per cent; and Alaska cedar, 3 per cent. The total stand of saw timber in this forest is about 78,500,000,000 feet, board measure. The character of the stand, distance from markets, and availability of water power favor the development of pulp and paper manufacture as the principal utilization, but lumber and other products will always be of importance, particularly in meeting the local needs and supplying local industry. At the same time, lumber of the more valuable kinds and grades should furnish an important item of export.

CHUGACH NATIONAL FOREST

The northern section of the coastal forest includes the important timbered areas extending from the Prince William Sound region to Cook Inlet. Practically all of the merchantable timber in this section is included within the Chugach National Forest. This forest also includes a small amount of the type of timber found in the interior of Alaska as represented by white spruce and Alaska white birch, which reaches tidewater at the head of Cook Inlet. The forest is quite similar to that of southeastern Alaska, except that no red cedar is found, some additional species are present, and the trees are smaller and on the whole contain less clear lumber.

The principal species in the Chugach National Forest occur in the following percentages: Western hemlock, 65 per cent; Sitka spruce, 22 per cent; white spruce, 11 per cent; cottonwood, 1 per cent; Alaska white birch, 1 per cent (*9*). Some mountain hemlock also is to be found. The total stand of the Chugach National Forest is approximately 6,260,000,000 feet, board measure (*20*).

Considerable quantities of timber are cut for local use, which includes sales of ties and lumber for the two railroads which touch this forest. Because of distance from market no lumber exports are at present made from this region, although it is possible that a demand will develop for the hardwoods, particularly birch. As is the case with the Tongass National Forest, the timber is also suitable for pulp and paper purposes.

INTERIOR FORESTS

The forests of interior Alaska are confined chiefly to the river basins and are of the woodland type, very slow in growth and very light in stand. While of great local value, they can not compare in commercial importance to the forests of the coastal type.

The interior forests have received so little study and are distributed over such large areas that no close estimate can be made of their extent. They are on the unreserved public domain of the United States and in general have had but little, if any, fire protection (*8*). Millions of acres have been burned within recent years. The area of the interior forests has been conservatively estimated at 50,000,000 acres, bearing at least 10 cords per acre, which gives a total volume of not less than 500,000,000 cords. It is unlikely that much of this timber will ever reach the general market, but it has high potential value for local use in connection with the development of the mining and agricultural resources of the vast region over which it occurs.

The principal tree species found in the interior forests are white spruce (pl. 4, A), Alaska white birch (pl. 4, B), Kenai birch, balsam poplar, aspen, black spruce, and tamarack. Of these white spruce is the most important (pl. 5, A), although Alaska white birch comprises a large percentage of the stand, and in some places occurs in almost pure stands. Balsam poplar and aspen (pl. 5, B) are found mainly along the streams. Black spruce frequents the swampy areas and is of comparatively little importance.

TIMBER PRODUCTION, EXPORT, AND YIELD

For the year 1929, the timber cut on the two national forests of Alaska amounted to 47,462,000 feet, board measure, with a stumpage value of $71,409. In 1929, 2,405,000 board feet of "wood, timber, and lumber," valued at $140,031, were shipped to other parts of the United States; and a total of 163,251 board feet of sawed lumber, valued at $4,738, were shipped to foreign countries (*23*).

The studies of yield have not progressed far enough to indicate definitely the amount of timber that can be produced in a second crop in a given number of years. However, sufficient has been done in the case of the Tongass National Forest to indicate that in southeastern Alaska the rotation for pulpwood is likely to be between 85 and 100 years, and that the crop produced in this period will have a volume per acre at least twice the average volume now found in the virgin commercial forest. Allowing 90 years as a rotation period for pulpwood, and assuming the present virgin timber to be entirely cut in this period, approximately 1,500,000 cords of wood of 600 board feet each can be removed from the Tongass National Forest yearly in this period. This output is sufficient to produce not less than 1,000,000 tons of newsprint a year. As the new crop of timber in which cutting will begin after 90 years will have at least twice the volume per acre of the virgin stand, a plan of forest management based on a sustained yield of 1,500,000 cords of pulpwood should prove to be conservative (*10*).

DESCRIPTION OF SPECIES

A general description of the characteristics, range, supply, production, properties, and uses of each of the Alaska species [4] is presented. In referring to the various physical and mechanical properties, a graduated set of descriptive terms, each corresponding to a

[4] The names of species appearing in this bulletin are the standard common names given in Check List of the Forest Trees of the United States, Their Names and Ranges (*18*).

certain numerical range of the property under consideration, is used to permit a more accurate evaluation of the property, and to afford a uniform basis of comparison between species. These terms are used in connection with the following properties: Weight, strength in bending and compression, stiffness, hardness, shock resistance, and shrinkage. Descriptive terms are also given for ease of kiln drying, ability to stay in place, workability, nail-holding ability, ease of gluing, and resistance to decay, although for these properties sufficiently complete information is not available on most species to permit as accurate a classification as is desired.

The complete set of terms for the above properties, applicable to all species, is presented in Table 1. An examination of this table will give a background for appraising the relationship of each term to that of the others. The index figures in column 1 of Table 1 are suggested as a numerical scale for expressing the degree to which a species possesses each of the various properties, and thus might be employed in lieu of the corresponding descriptive term. In the species descriptions which follow, however, only the descriptive terms are used. The classification limits given in Table 1 apply to specific gravity only although other classification limits have been set up and used for shrinkage and the mechanical properties.

TABLE 1.—*Comparative terms used in describing wood properties*

Index figure	Specific gravity or weight		Descriptive terms for—	
	Classification limits (specific gravity)	Descriptive terms	Strength in bending and compression	Stiffness
1	Below 0.20	Extremely light	Extremely weak	Extremely limber.
2	From 0.20 to 0.25	Exceedingly light	Exceedingly weak	Exceedingly limber.
3	From 0.25 to 0.30	Very light	Very weak	Very limber.
4	From 0.30 to 0.36	Light	Weak	Limber.
5	From 0.36 to 0.42	Moderately light	Moderately weak	Moderately limber.
6	From 0.42 to 0.50	Moderately heavy	Moderately strong	Moderately stiff.
7	From 0.50 to 0.60	Heavy	Strong	Stiff.
8	From 0.60 to 0.72	Very heavy	Very strong	Very stiff.
9	From 0.72 to 0.86	Exceedingly heavy	Exceedingly strong	Exceedingly stiff.
10	Above 0.86	Extremely heavy	Extremely strong	Extremely stiff.

Index figure	Descriptive terms for—		
	Hardness	Shock resistance	Shrinkage
1	Extremely soft	Extremely low	Extremely small.
2	Exceedingly soft	Exceedingly low	Exceedingly small.
3	Very soft	Very low	Very small.
4	Soft	Low	Small.
5	Moderately soft	Moderately low	Moderately small.
6	Moderately hard	Moderately high	Moderately large.
7	Hard	High	Large.
8	Very hard	Very high	Very large.
9	Exceedingly hard	Exceedingly high	Exceedingly large.
10	Extremely hard	Extremely high	Extremely large.

Index figure	Descriptive terms for—					
	Ease of kiln drying	Ability to stay in place	Workability	Nail-holding ability	Ease of gluing	Resistance to decay
2	Very easy	Very good	Very easy	Very high	Very easy	Very high.
4	Easy	Good	Easy	High	Easy	High.
6	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate.
8	Difficult	Poor	Difficult	Low	Difficult	Low.
10	Very difficult	Very poor	Very difficult	Very low	Very difficult	Very low.

ALASKA WHITE BIRCH

(*Betula neoalaskana* Sargent)

OTHER NAMES

Alaska white birch is also known as Alaska birch, white birch, and yellow birch. It should not, however, be confused with paper birch (*Betula papyrifera* Marshall) which is often called white birch, or with *B. lutea* Michaux which is officially called yellow birch.

GENERAL DESCRIPTION

Alaska white birch is one of the few hardwood species found in Alaska, and has the densest wood of the Alaska tree species. The heartwood is light reddish brown; the moderately wide sapwood is practically white. The wood has a fine even texture, and finishes well. The trees are of relatively slow growth; the test material from 10 trees of one site near Whitney averaged 29 rings per inch. (Pl. 6, A.)

DISTRIBUTION AND GROWTH

The general range of Alaska white birch is from the Saskatchewan Valley to the Yukon River Valley (*18*).

The most important birch forests in Alaska are those of the upper Cook Inlet region. The Alaska white birch-white spruce type is the typical forest of this region (*7*). It occupies the rolling bench land above the bottoms and extends up the lower slopes of the foothills to an elevation of about 800 feet. Here the Alaska white birch is associated with white spruce (*Picea glauca* (Moench) Voss), Kenai birch (*Betula kenaica* Evans), and aspen (*Populus tremuloides*). The trees at an age of from 100 to 130 years on the more favorable sites attain a height of 60 to 70 feet and a diameter of 10 to 14 inches, although the average diameter breast high is from 8 to 10 inches. Occasionally a diameter of 24 inches is reached.

In trees over 8 inches diameter breast high, the heartwood for varying distances from the pith is commonly stained, and frequently advance stages of decay are present.

SUPPLY

No intensive cruise has been made as a basis for accurately determining the amount of Alaska white birch, but the total stand in the upper Cook Inlet region is roughly estimated as about 2,000,000,000 feet, board measure.

PRODUCTION

In the vicinity of the larger cities, like Anchorage, thousands of cords of Alaska birch have been cut for fuel. Prior to the construction of the Alaska Railroad, when wood was the only available fuel, the rate of cutting was higher than it is at present. No figures are available on the total or present yearly volume of the cut. Industrial uses for the wood have not yet been developed.

PROPERTIES

The wood of Alaska white birch is moderately heavy, moderately strong in bending and compression, stiff, moderately hard, high in

shock resistance, and has a very large shrinkage. It resembles paper birch more closely in its mechanical properties than any of the other birches. Less definite information is available on certain of the other properties. Judging from observations on the material tested for strength, Alaska white birch would be expected to rank as moderate in ease of kiln drying, good in ability to stay in place, easy to work, high in nail-holding ability, difficult to glue, and low in resistance to decay. Like the other species of birch, it is diffuse-porous in structure. It has a fine, even texture, and should take finishes and stains satisfactorily.

PRINCIPAL USES

Alaska white birch has so far been used but little except locally for fuel and mine props. Since it is similar in structure to the other birches and falls between paper birch (*Betula papyrifera*) and yellow birch (*B. lutea*) in its mechanical properties, it would seem safe to infer that sound material of Alaska white birch would be adaptable to many of the same uses. Drake (*7*) reports that tests were made of the possibilities of Alaska white birch for shoe pegs, spools, and bobbins, and it was found highly satisfactory; also that furniture made of this birch has a pleasing appearance and when stained resembles mahogany.

The birches of the United States are used for planing-mill products, furniture, musical instruments, woodenware and novelties, kitchen ware, athletic goods, broom and mop handles, brush and tool handles, fruit packages, boxes and crates, baskets, shoe lasts, clothespins, bungs, paper-roll plugs, skewers, golf tees, arrow shafts, spools, and dowels. Paper birch is used for turned products, principally spools, novelties, toys, toothpicks, and shoe pegs. Birch is also one of the principal woods used for hardwood distillation in the production of wood alcohol, acetate of lime, and charcoal.

ALASKA CEDAR

(*Chamaecyparis nootkatensis* (Lambert) Sudworth)

OTHER NAMES

Alaska cedar is also known as yellow cedar (Oregon), Sitka cypress (Oregon, California), yellow cypress (Oregon, Washington), Nootka cypress (California), Nootka sound cypress (England), Alaska sound cypress (California), Alaska cypress (California), and Alaska yellow cedar (trade).

GENERAL DESCRIPTION

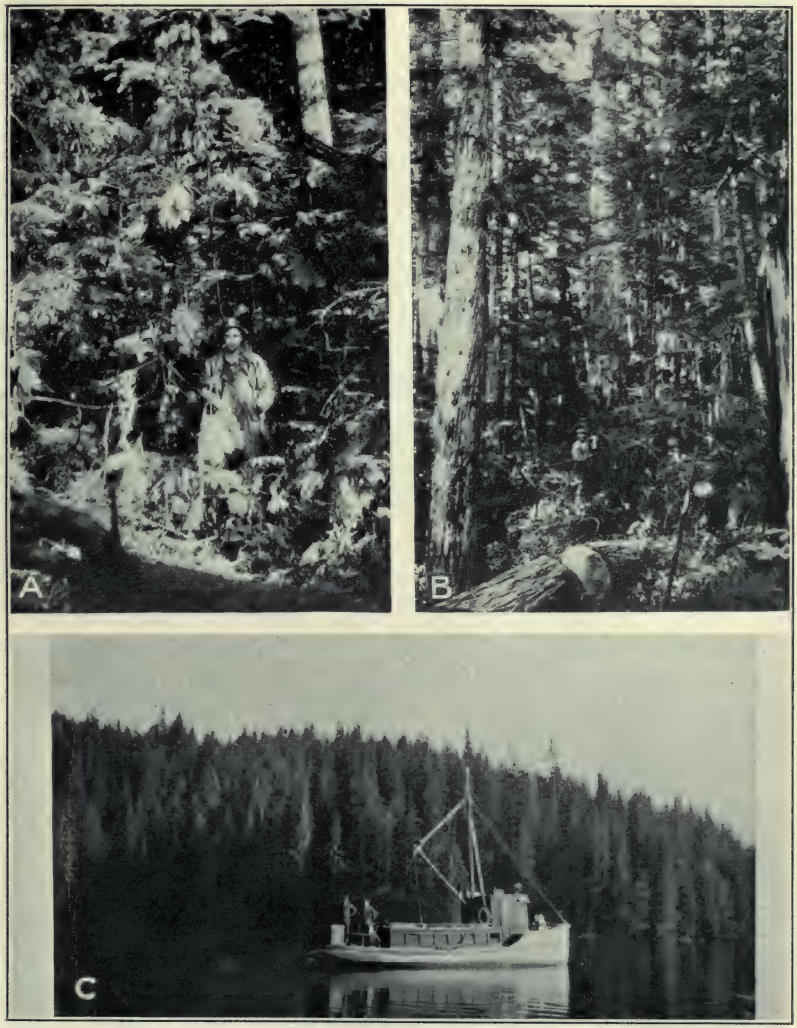
Alaska cedar is a little-known softwood which is closely related botanically to southern white cedar (*Chamaecyparis thyoides* (Linnaeus) Britton, Sterns, and Poggenberg) and Port Oxford cedar (*C. lawsoniana* (A. Murray) Parlatore). The heartwood is a bright clear yellow; the sapwood is noticeably lighter in color, particularly when green, and forms but a comparatively narrow band. The wood contains a natural volatile oil, which gives it a distinctive odor and seems to add a slight gloss to a newly cut smooth side-grain surface. It has a fine, even texture, and is relatively straight-

M14687F

DENSE FORESTS OF HEMLOCK AND SPRUCE GROW ALONG THE SHORE LINES OF THE VAST NETWORK OF PROTECTED WATERWAYS IN SOUTHEASTERN ALASKA

M 14688F

IMMATURE STAND OF SITKA SPRUCE AND WESTERN HEMLOCK IN SOUTHEASTERN ALASKA



M16554F

A, Typical view of the dense understory in the Tongass National Forest; B, western red cedar in the Tongass National Forest; C, waterways furnish ready access to the principal forest stands of Alaska, making expensive logging railroads unnecessary

M14692F M14689F

A, White spruce near Fairbanks in interior Alaska; B, stand of pure white birch in interior Alaska

M14690F M14691F

A, White spruce and white birch in interior Alaska; B, forest of white birch, balsam poplar, and aspen in interior Alaska

M 14286F

A, Alaska white birch selected for test at the Forest Products Laboratory; B, western hemlock from the Chugach National Forest selected for test at the Forest Products Laboratory. These logs are from representative mature trees

grained. The virgin trees are of slow growth, as shown by the average of 23 rings per inch for the specimens tested from Alaska.

DISTRIBUTION AND GROWTH

Alaska cedar grows in the Pacific coast region of North America from southwestern Alaska southward to northern Oregon. It is widely distributed in southeastern Alaska and reaches the best development at elevations between 500 and 1,200 feet. It generally reaches a height of about 80 feet and a diameter of 2 to 3 feet. Trees 4 to 5 feet in diameter and 100 feet high are common (*19*). Trees 15 to 20 inches in diameter are generally 200 to 300 years old.

Alaska cedar grows in southeastern Alaska in combination with western red cedar, in pure stands and as scattered trees in the spruce-hemlock forests. The best trees are found in the spruce-hemlock forests, and are logged in connection with saw timber and piling operations. To obtain any considerable quantity, however, it is necessary to log the cedar stands which are usually in patches of one-half million feet or less. These patches are most frequently found on steep slopes some distance inland from tidewater so that the cost of logging is consequently high. While Alaska cedar lumber is very resistant to decay, the overmature trees are inclined to be defective, many containing as much as 25 to 30 per cent rot at the center (*9*).

SUPPLY

Estimates of the total stand of Alaska cedar are lacking. A rough estimate of the total stand in Alaska, British Columbia, Washington, and Oregon is about 10,000,000,000 board feet, with about 2,500,000,000 board feet in Alaska.

PRODUCTION

No definite figures are available on the amount of Alaska cedar cut in Alaska. The cut of cedar in Washington in 1928 was 151,970,000 board feet. Under "cedar" is included western red cedar, Alaska cedar, and several other species. It is estimated that between 5 and 10 per cent of this cut in Washington, roughly 10,000,000 board feet, was Alaska cedar. The production of lumber from Alaska cedar may be expected to increase considerably.

PROPERTIES

The wood of Alaska cedar is moderately light in weight, moderately weak in bending and compression, moderately stiff, moderately hard, moderately high in shock resistance, and has a small shrinkage. Less definite information is available on certain of the other properties. On the basis of approximate classifications Alaska cedar is estimated to rank as very easy to kiln dry, good in ability to stay in place, very easy to work, low in nail-holding ability, easy to glue, and very high in resistance to decay. In resistance to decay, the heartwood of Alaska cedar ranks with that of Port Orford cedar, western red cedar, southern cypress, and redwood. Alaska cedar and Port Orford cedar differ from western red cedar and most other species in that the spring wood is firmer and consequently they have

a much more uniform texture which makes them admirably adapted for such purposes as carving, veneers, battery separators, and where smooth wear is desirable. Alaska cedar is reputed locally not to hold paint well, particularly on boat hulls, but experiments on dry samples at the Forest Products Laboratory have not shown any unusual difficulty. Like other species, it would not be expected to take paint well if not well dried, and it is possible that any difficulty encountered may be due to this cause.

The static and impact bending specimens of Alaska cedar exhibited during test an evidence of toughness not usually found in a softwood species of its density. Some of the 2 by 2 by 30-inch bending specimens when green deflected 6 inches without complete failure, the compression tending to distribute itself as in some of the hardwoods, rather than sharply localizing as is more characteristic of the softwoods. This indicates that Alaska cedar may be adapted to uses where bending to form is required, and its properties are otherwise suitable, but additional tests would be necessary to determine whether or not this is a species characteristic, or merely of occasional occurrence. The behavior observed is contrary to reports that Alaska cedar is inclined to be brash.

PRINCIPAL USES

A large part of the cut of Alaska cedar is used locally for poles, interior finish, furniture, small boat hulls, cabinetwork, and novelties. It is considered valuable for patterns, toys, turned articles, chests, battery boxes, and battery separators. It is also reported as used for picture frames, brush backs, venetian blinds, curtain poles, sash, doors, stair work, millwork, and store and office fixtures. A small amount is shipped to Japan in log form. A specialty use of Alaska cedar is for patterns. It has long been the customary wood of the Alaska Indians for canoe paddles.

WESTERN RED CEDAR

(*Thuja plicata* D. Don)

OTHER NAMES

Western red cedar is also known as red cedar (Idaho, Oregon, Washington, Montana, British Columbia), canoe cedar (Oregon, Washington), arborvitae (California), shinglewood (Idaho), gigantic cedar (California), cedar (Oregon, Montana, Idaho, Pacific coast trade), gigantic red cedar (California literature), western cedar, Washington red cedar (trade), Washington cedar (trade), Idaho cedar (trade), Oregon cedar (trade), California cedar (trade), British Columbia cedar (trade), Pacific arborvitae (literature), western arborvitae (literature), red cedar pine (trade), Lobb's arborvitae (England), Pacific red cedar (California literature), and giant arborvitae (literature and horticulture).

GENERAL DESCRIPTION

Western red cedar is a moderately slow-growing, long-lived tree that is closely related to the well-known northern white cedar

(*Thuja occidentalis* Linnaeus). The heartwood is a reddish brown; the narrow sapwood is white. The reddish color of the heartwood is thought to be due partly to certain extractives, which appear to be responsible for the high resistance of the wood to decay. The wood has a distinctive odor characteristic of the cedars. The narrow summer-wood bands are distinctly darker and harder than the adjacent spring wood. The wood has a fine, moderately even texture.

DISTRIBUTION AND GROWTH

Western red cedar grows principally in a belt along the western coast of North America, extending from the southern half of southeastern Alaska to northern California. In Alaska it reaches its best development below an elevation of 500 feet.

Western red cedar has a characteristic buttressed base, tapering trunk, and conical crown; it sometimes grows in small pure stands but generally in mixture with other species, by which it is frequently overtopped. The tree is capable of enduring shade but under such conditions the rate of growth is reduced. Large trees in southeastern Alaska are from 100 to 130 feet high and 3 to 6 feet in diameter. The mature trees are limby, heavily tapered, and are subject to severe heart rot, but trees of pole size are well formed and sound. In Alaska the best trees are those occurring as scattered individuals or in small groups (pl. 3, B) in stands of hemlock and spruce. The trees of the pure cedar type of forest average somewhat poorer in quality but are sufficiently good to be classed as merchantable. The open stands of cedar and other species found so commonly on the swamp soils are uniformly poor in quality and are not considered merchantable, the trees being short, limby, and defective.

SUPPLY

The stand of western red cedar in the United States is estimated at 53,348,000,000 board feet. Of this total approximately 49,000,000,000 board feet is in the Pacific coast region and the remainder in the Rocky Mountain region (*20*). The stand in Alaska is estimated at 2,350,000,000 board feet (*10*).

PRODUCTION

The cut of western red cedar lumber in the United States, exclusive of Alaska, in 1928 is estimated at about 200,000,000 board feet. In 1928 a total of about 5,342,000,000 shingles, equivalent to 534,000,000 board feet, were produced in the United States proper (*21*). It is probable that at least an additional 100,000,000 board feet is cut for poles, posts, and piling. The cut of western red cedar in Alaska is, however, still very small.

PROPERTIES

The wood of western red cedar is light in weight, weak in bending and compression, moderately limber, moderately soft, low in shock resistance, and has a very small shrinkage. On a basis of approximate classification, western red cedar is estimated to rank as moderate in ease of kiln drying, good in ability to stay in place, very easy to

work, very low in nail-holding ability, moderate in ease of gluing, and very high in decay resistance. In decay resistance, the heartwood ranks with that of Alaska cedar, Port Orford cedar, redwood, and southern cypress.

PRINCIPAL USES

Western red cedar is used principally for shingles, lumber, poles, posts, and piling. About nine-tenths of all the shingles manufactured in the United States are western red cedar. The decay resistance, ease of working, and lightness of the wood make it highly satisfactory for this purpose. Considerable quantities of western red cedar lumber are used for siding, tank stock, boat building, porch columns, hothouse construction, and for other purposes where decay resistence and ease of working or lightness are especially desirable. Western red cedar is also reported as used for beehives, finish, trim, boxes, carving, caskets, ceiling, furniture parts, incubators and brooders, moldings, patterns, pencils, picture frames, window frames and sash, light cooperage, ice-cream tubs, core stock, drafting boards, fixtures, and fishing-net floats.

Western red cedar poles on account of their desirable properties and form and size are shipped from various northwestern States to nearly all parts of the United States. For posts the wood is widely used; for piling it is used less, as it is liable to crush under the blows of the pile driver. Although the heartwood of western red cedar is very decay resistant it is nevertheless good practice to apply a preservative to posts and poles, particularly to prolong the life of the nondurable sapwood. The western red cedar of Alaska will probably be utilized in fairly large quantities after the depletion of the virgin stands in Washington and British Columbia has progressed farther.

NORTHERN BLACK COTTONWOOD

(*Populus trichocarpa hastata* Henry)

OTHER NAMES

Northern black cottonwood is also known as Cottonwood (Oregon), balsam cottonwood, balm (Oregon), and black balsam poplar.

GENERAL DESCRIPTION

Northern black cottonwood is a lightweight hardwood (broad-leaved) species of the Pacific Northwest, which is closely related to the aspens and poplars. The wood is grayish white to light brown. It is diffuse porous, and has a fine, even texture. The annual rings are scarcely noticeable. The sapwood is wide and not clearly defined, but merges gradually into the heartwood. Northern black cottonwood is a tree of normally rapid growth, but in maturity and overmaturity the rate of growth is much slower.

DISTRIBUTION AND GROWTH

Northern black cottonwood occurs from southern Alaska to California and extends inland as far as in western Montana. It grows best at lower levels on river bottoms and sand bars. In Alaska it

occurs in quantity only on the valley floors of a few large mainland streams, principally the Stikine and Taku Rivers, where mature trees reach an average diameter of 3 feet and a height of 80 to 90 feet. Though black-heart and black knots are common in mature trees, extensive areas of immature trees of excellent quality are found.

SUPPLY

The total stand in the continental United States of the three cottonwoods—eastern, swamp, and northern black—of saw-timber size is estimated at 7,500,000,000 board feet, of which black cottonwood comprises about 1,500,000,000 board feet. The supply in southeastern Alaska is relatively small, although exact figures are lacking.

PRODUCTION

The term "cottonwood" as used in the lumber-cut statistics of the United States includes the eastern, swamp, and black cottonwoods and in addition the aspens and balsam poplar. It is difficult, therefore, to give any very close figures for northern black cottonwood. The total cut of black cottonwood lumber in the United States, including Alaska, is relatively small, being estimated roughly as 2,500,000 board feet in 1928. The cut in Alaska has so far been negligible.

PROPERTIES

Northern black cottonwood is light in weight, weak in bending and compression, moderately limber, soft, moderately low in shock resistance, and has a moderately large shrinkage. It is estimated to rank as moderate in ease of kiln drying, poor in ability to stay in place, easy to work, very low in nail-holding ability, easy to glue, and very low in resistance to decay.

PRINCIPAL USES

Lumber cut from eastern, swamp, and black cottonwood is used principally for boxes and crates. Although northern black cottonwood is not high in nail holding, its light weight and ability to take nails without splitting combined with a good color for stenciling and lack of odor make it suitable for a wide variety of boxes. Over half of the cottonwood lumber goes into boxes. Other uses reported for cottonwood lumber include automobile-body work, planing-mill products, agricultural implements, refrigerators, woodenware, laundry appliances, kitchen cabinets, trunks, furniture, and millwork.

Cottonwood veneer in the form of plywood is widely used in furniture and musical instruments and for similar purposes where thin panels are needed.

Other important cottonwood products are paper (generally high-grade book paper made by the soda process) and excelsior. The light color, fairly straight grain, and uniform texture of cottonwood make it well fitted for excelsior manufacture.

MOUNTAIN HEMLOCK

(*Tsuga mertensiana* (Bongard) Sargent)

OTHER NAMES

Mountain hemlock is also known as Williamson's spruce (California), weeping spruce (California), alpine spruce (California), hemlock spruce (California), Patton's spruce, alpine western spruce (literature), black hemlock (literature), Patton's hemlock (Washington), and alpine hemlock (Alaska, Washington, California).

GENERAL DESCRIPTION

Mountain hemlock is a near relative of western hemlock (*Tsuga heterophylla* (Rafinesque) Sargent), and is somewhat similar in appearance, but the tree is smaller and the trunk has more taper and is less clear of branches and knots. The heartwood is a pale reddish brown; the sapwood is moderately thin. The summer wood is quite pronounced, and is distinguishable from the lighter appearing spring wood. The wood has a moderately fine and moderately even texture. The mountain hemlock from Alaska tested at the Forest Products Laboratory averaged 29 growth rings per inch.

DISTRIBUTION AND GROWTH

Mountain hemlock grows in the mountains of the Pacific coast region of North America from southern Alaska to the high Sierras of California, extending as far eastward as Idaho and Montana. It is mainly a timber-line tree, but in Alaska it also grows near sea level on rocky sites. Mountain hemlock at its best occasionally reaches a height of 100 to 125 feet and a diameter of 30 to 40 inches. Such trees, however, are uncommon. At the other extreme, it sprawls among the rocks to but a few feet in height on bleak windswept crests.

SUPPLY AND PRODUCTION

Because mountain hemlock is mainly confined to the higher altitudes, it is largely inaccessible. The supply is relatively limited and, as a whole the production is small, and the species is not important commercially. There are places, however, particularly in the Chugach National Forest, where the species is found near sea level, and as a result it has been cut with western hemlock and spruce for ties used for the Alaska Railroad.

PROPERTIES

Mountain hemlock is one of the few species in which shrinkage and the principal strength properties all closely and uniformly correspond to what would be expected for its density. Most species have at least one property which differs from the general law. The wood of mountain hemlock is slightly above the median of the different species, and may be classed as moderate in its properties. Hence it is moderately heavy, moderately strong in bending and compression, moderately stiff, moderately hard, moderately high in shock resistance, and has a moderately large shrinkage. Experience with this

wood is very limited. A few samples were machined satisfactorily and finished smoothly.

PRINCIPAL USES

Mountain hemlock at present is but little used and is not important commercially. Judging from its density, strength properties, and appearance, it would seem to be suitable for such uses as those for which western hemlock is employed.

WESTERN HEMLOCK

(*Tsuga heterophylla* (Rafinesque) Sargent)

OTHER NAMES

Western hemlock is also known as hemlock spruce (California), hemlock (Alaska, Oregon, Idaho, Washington, Montana, and trade), western hemlock spruce (literature), California hemlock spruce, western hemlock fir (England), Prince Alberts fir (England), Alaska pine (northwestern lumbermen), west coast hemlock (trade), Pacific hemlock (trade), Pacific coast hemlock (trade), and Pacific (western) hemlock (trade).

GENERAL DESCRIPTION

Western hemlock is related botanically to eastern hemlock (*Tsuga canadensis* (Linnaeus) Carriere), but differs from it in appearance, in characteristic defects, and, to a lesser extent, in its mechanical properties. The general color is a pale reddish brown, with the sapwood very similar and generally not easily distinguishable from the heartwood when dry. The summer-wood bands, although marked, do not contrast decidedly with the lighter-colored spring wood. The contrast is less pronounced than in Douglas fir and southern yellow pine, but more so than in Sitka spruce and northern white pine. The wood has a moderately fine and moderately even texture and is nonresinous. It has a sour odor when green, but is odorless and tasteless when dry. The annual growth rings are usually comparatively uniform in width. Western hemlock from Alaska, however, appears to have a somewhat slower average growth than that from Washington and Oregon, and to the extent that this is true the Alaska-grown material should exhibit a more even texture.

DISTRIBUTION AND GROWTH

Western hemlock grows in the Pacific coast region of North America from southern Alaska to northern California and western Montana. In Alaska the stands of mature trees of about 200 to 250 years in age range from 2 to 4 feet in diameter and are about 150 feet in height. (Pl. 6, B.) The tree has a long, slender bole, and a short narrow crown. The trees are clear of branches well to the top. They are commonly sound when young, but when mature and overmature at diameters of 3 to 3½ feet, heart rot is very prevalent; many of these old overmature trees are so defective as to be classed as unmerchantable. The stands vary from almost pure to admixtures of Sitka spruce, western red cedar, and Alaska cedar. Western hemlock is the most abundant and important species in Alaska. It reproduces

prolifically, grows well on a variety of soils, and is very tolerant of shade. In Alaska, hemlock trees on the poorest sites and occurring as scattered trees in pure spruce stands frequently have deeply fluted lower trunks. The lumber from these fluted trunks often contains many large bark pockets and decay spots. In the commercial forests as a whole, however, fluting is not an important factor.

SUPPLY

The total stand of western hemlock saw timber in the United States, including Alaska, is about 149,000,000,000 board feet, of which 62,000,000,000 board feet are in Alaska.

PRODUCTION

The cut of western hemlock lumber in the United States in 1928 was about 1,550,000,000 board feet, and in Alaska 7,853,000 board feet (*21*). The total production of western hemlock for lumber has shown a tenfold increase in the past 20 years. It is expected, however, that the principal future cut of western hemlock in Alaska will be for pulpwood, as the wood is well adapted for that use.

PROPERTIES

The wood of western hemlock is moderately light in weight, moderately weak in bending and compression, moderately stiff, moderately hard, moderately low in shock resistance, and has a moderately large shrinkage. Less definite information is available on the other properties. Western hemlock is estimated to rank as moderate in ease of kiln drying, moderate in ability to stay in place, moderate in workability, moderate in nail-holding ability, very easy to glue, and very low in resistance to decay. Western hemlock takes paint satisfactorily, being about equal with eastern hemlock and the spruces.

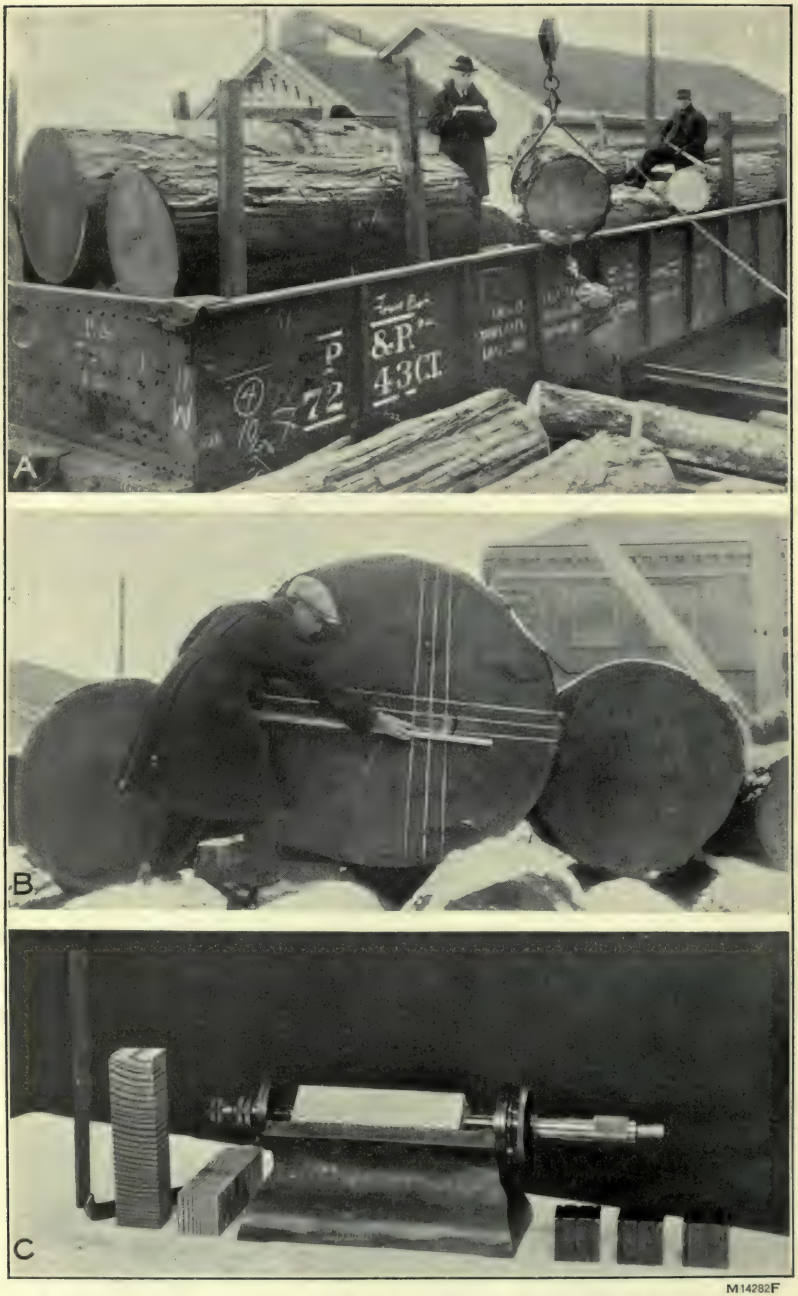
PRINCIPAL USES

The most important use of western hemlock is for building material, such as common boards and shiplap, sheathing, studding, joists, subfloors, floors, finish, lath, trim, millwork, and many other items. It is also used for shipping containers, cooperage, railway cars, ladders, concrete forms, furniture, veneer, poles, piles, railroad ties, and mine timbers (*12*). Tests by the United States Bureau of Animal Industry indicate that it may be used for butter containers without imparting sufficient woody flavor to be commercially objectionable. Western hemlock has an established high value as a pulpwood, particularly in Alaska, because of the relatively pure stands, and because water power is conveniently available for manufacture.

Hemlock is used extensively as piling for the construction of fish traps, which are operated in the coastal waters of Alaska by the salmon-canning industry. Many of the sticks cut for this purpose are from 90 to 130 feet in length. Hemlock ties are now sawn in quantity by the local mills for use on the Alaska Railroad. Very little hemlock lumber is being cut in Alaska because it can not profitably be shipped to the general market in competition with Puget

M 14281F

A, Mature balsam poplar trees in the Chugach National Forest. This species attains a height of about 100 feet; B, butt log of Sitka spruce from the Tongass National Forest awaiting manufacture at an Alaska sawmill; C, Sitka spruce in the hemlock-spruce type of forest on the southeastern coast of Alaska



M14282F

A, A shipment of test material from Alaska being unloaded at the Forest Products Laboratory; B, a Sitka spruce log being marked at the Forest Products Laboratory for sawing into small, clear specimens for mechanical tests; C, method of measuring specimens at the Forest Products Laboratory to determine radial and tangential shrinkage

Sound hemlock. The consumption is increasing, however, as the merits of western hemlock lumber become better known.

BALSAM POPLAR

(*Populus balsamifera* Linnaeus)

OTHER NAMES

Balsam poplar is also known as balsam (New Hampshire, New York, Wisconsin, Michigan, Minnesota, Nebraska, Montana, Ohio, Ontario), balm-of-Gilead (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Michigan, Nebraska, Minnesota, North Dakota, Ontario), cottonwood (Idaho), poplar (Wisconsin, Minnesota), balsam poplar (New Hampshire, Nebraska, Minnesota), tacamahac (Minnesota), baumier (Quebec), and rough-barked poplar (Hudson Bay region).

GENERAL DESCRIPTION

Balsam poplar (pl. 7, A) is a hardwood species of light weight, which is closely related botanically to the aspens and cottonwoods. It should not be confused with yellow poplar (*Liriodendron tulipifera* Linnaeus), the well-known species of the eastern United States, to which it bears no botanical relation.

The heartwood of balsam poplar is a light brown; the moderately thick sapwood nearly white. The wood is diffuse porous, and, consequently has a fine, even texture. The tree is normally of rapid growth; the trees collected for test from Girdwood, Alaska, averaged 14 rings per inch.

DISTRIBUTION AND GROWTH

Balsam poplar grows principally in Alaska and Canada. Its range extends from Alaska to Hudson Bay and Newfoundland and southward to the United States along the Canadian border from Maine to Oregon. It is distinctly a northern tree and parts of its range are characterized by a short growing season and long severe winters; conditions too severe for the existence of most other trees. It is confined mainly to alluvial bottom lands and to the borders of streams and swamps in moist, sandy and gravelly soils. Seeds are abundant and are scattered widely by the wind. The trees secured for test from Girdwood averaged 88 feet in height and ranged from 78 to 98 feet. They averaged 23 inches in diameter and 162 years of age.

SUPPLY

While the total stand of balsam poplar saw timber (exclusive of pulpwood) in the United States proper is estimated very roughly at 1,250,000,000 board feet, definite estimates are lacking for the Alaska supply. The stand of balsam poplar, if the smaller pulpwood sizes are included, is much less than that of the aspens.

PRODUCTION

There has been but little demand for balsam poplar in Alaska, and, consequently, the cut has been small. It is estimated that in the United States proper approximately 6,000,000 board feet of bal-

sam poplar lumber has been produced annually during the years 1922 to 1927. Balsam poplar pulp wood is also cut with the cottonwoods and aspens without distinction. The total annual cut of balsam poplar for various purposes, including pulpwood, is estimated roughly at from 12,000,000 to 15,000,000 board feet for 1927.

PROPERTIES

The wood of balsam poplar is light in weight, exceedingly weak in bending and compression, limber, soft, low in shock resistance, and has a moderately small shrinkage. It is considered to rank as moderate in ease of kiln drying, poor in ability to stay in place, easy to work, very low in nail-holding ability, easy to glue, and very low in resistance to decay. The wood has excellent pulping qualities and is well suited for paper making both by the sulphite and soda processes.

PRINCIPAL USES

Balsam poplar is used principally for box and crate lumber and for pulp wood in the manufacture of paper. A small amount of the lumber goes into the manufacture of containers for druggists' supplies, and some of the high-grade logs are cut into veneer from which various kinds of fruit baskets are made. A small amount of balsam poplar is also used for making excelsior.

SITKA SPRUCE

(*Picea sitchensis* (Bongard) Carriere)

OTHER NAMES

Sitka spruce is also known as tide-land spruce (California, Oregon, Washington), Menzies' spruce, western spruce, great tide-land spruce (California, literature), yellow spruce (trade), western Sitka spruce (trade), silver spruce (trade), Sequoia silver spruce (trade), spruce (trade), and west coast spruce (trade).

GENERAL DESCRIPTION

Sitka spruce, while related botanically to the white spruce, so eclipses the latter in size as to make it much more important, commercially. The heartwood is light reddish brown, the sapwood nearly white. The wood is classified as nonporous and has a fine, moderately uneven texture. The tree, except in overmaturity, is of moderately rapid growth in Alaska. The test material from Girdwood averaged 23 rings per inch, and the large trees from near Ketchikan averaged 17.

DISTRIBUTION AND GROWTH

Sitka spruce is found along the Pacific coast region from Alaska to northern California, extending inland about 50 miles. It is reported to occur from sea level to as high as 5,000 feet, but it grows mainly at altitudes of less than 1,500 feet. It forms pure forests, but also occurs in mixed stands. In the usual mixed forest the faster-growing and more light-demanding spruces are larger in diameter than the western hemlock with which they are associated and exceed them in height.

The tree is ordinarily 80 to 125 feet high and from 3½ to 6 feet in diameter (*19*). In the Tongass National Forest the average mature tree is about 160 feet high and 5 feet in diameter, but trees with a height of 200 feet and a diameter of 7 feet are common. (Pl. 7, B and C.) The largest known Sitka spruce in Alaska is 14½ feet in diameter at a point 6 feet above the ground (*10*). The trees from which test material from the Tongass National Forest were selected ranged from 4½ feet to 5¾ feet in diameter at the stump, with an average of 5 feet, and from 147 to 228 feet in height, with an average of 197 feet. The oldest tree was 757 years of age; the youngest 248. The trees selected for test from the Chugach National Forest were much smaller, averaging 17 inches in diameter, 80 feet in height, and 203 years of age.

Sitka spruce is commonly sound and straight grained, but on exposed sites is subject to spiral grain. The most common defect of overmature trees is butt rot.

SUPPLY

The estimated volume of Sitka spruce of commercial size on the Tongass National Forest is 15,800,000,000 feet, board measure (*10*), and on the Chugach National Forest about 1,400,000,000 feet, board measure. Alaska contains about two-fifths of the total supply of Sitka spruce.

PRODUCTION

Of the 571,917,000 board feet of spruce (all spruces) lumber produced in the United States in 1928, Oregon and Washington furnished over one-half, most of which was Sitka spruce. The production of spruce lumber in Alaska in 1928 was 22,748,000 board feet (*21*). Statistics show exports from Alaska to foreign countries of spruce boards amounting to 2,411,000 board feet in 1928 and 85,000 board feet in 1929.

The export of high-grade spruce lumber from Alaska started during the World War, and since then considerable quantities of clear spruce for airplanes and other special uses have been sent out by the local mills and transhipped through Seattle to North American and to foreign markets. Full cargo shipments of merchantable grade lumber are made at irregular intervals to Atlantic and trans-Pacific ports.

PROPERTIES

The wood of Sitka spruce is moderately light in weight, moderately weak in bending and compression, moderately stiff, moderately soft, moderately low in shock resistance, and has a moderately large shrinkage. It may be classed as easy to kiln-dry, good in ability to stay in place, easy to work, low in nail-holding ability, very easy to glue, and very low in resistance to decay. It is a nonporous wood and has a fine, moderately even texture.

Knots, when present, are usually sound. The wood contains small resin ducts, the direction of which on a flat-sawn surface indicates the direction of the grain, and is a useful guide in inspection for such uses as airplanes and ladders where strength is the controlling requirement.

Sitka spruce, in common with other softwood species, frequently contains compression wood. Compression wood is characterized by high density, wide rings, and a large percentage of summer wood. Although such material, because of its density and large amount of summer wood superficially presents certain external characteristics of the strongest and most desirable material, it is, nevertheless, unreliable as to strength and has an appreciable longitudinal shrinkage which causes it to warp and twist badly, particularly when present with normal wood. Fortunately, compression wood is not excessive in amount, is easily recognized, and, because of its warping tendencies, is likely to be culled before it reaches the finished product.

PRINCIPAL USES

Sitka spruce is an excellent material for airplane construction where its light weight and relatively high strength make it the most sought for species for such parts as wing beams and wing-rib cap strips. It is estimated that but 2 or 3 per cent of all the mill-run stock is suitable for airplane use, although selected logs are reported to yield as high as 7 per cent.

Sitka spruce has long been used for piano sounding boards because of the uniformity of structure obtainable, its high resonance properties, its freedom from defects, the large sizes available, and the ease of conditioning or seasoning.

Sitka spruce is also used extensively for ladders. Among its other uses are furniture, stringed musical instruments, refrigerator framework, ironing boards, washboards, clothes drying racks, laundry tubs, butter containers, baskets and hampers, fruit and vegetable containers, tanks, boxes and crates, oars, paddles, and building construction. Much of the low-grade lumber is manufactured into packing cases for the Alaska salmon industry.

In addition, Sitka spruce is probably the best species for pulpwood on the Pacific coast and compares favorably with the highly rated white spruce in this respect.

WHITE SPRUCE

(*Picea glauca* (Moench) Voss)

OTHER NAMES

White spruce is also known as single spruce (Maine, Vermont, Minnesota), bog spruce (New England), skunk spruce (Wisconsin, Maine, New England, Ontario), cat spruce (Maine, New England), spruce (Vermont), pine (Hudson Bay), double spruce (Vermont), blue spruce (Maine), eastern spruce (trade—in part), Canadian spruce, and Adirondack spruce (trade).

GENERAL DESCRIPTION

White spruce is a softwood species that has long been in popular favor and use. It is related botanically to several other species, the more important of which are Sitka spruce, red spruce, and Engelmann spruce. Of these, red, Sitka, and white spruce are very similar in their mechanical properties and may be used on a like basis in airplane construction.

The heartwood and the sapwood are practically white; consequently they are not readily distinguishable when dry. The wood in common with that of other coniferous species is classifield as nonporous. It has a fine, moderately uneven texture, and can be machined and worked easily. In Alaska the tree is of relatively slow growth; the test material obtained from near Matanuska averaged 22 rings per inch.

DISTRIBUTION AND GROWTH

White spruce grows over a wide area extending from Labrador to Hudson Bay and northwestward through Alaska to Bering Strait; extending southward to the Great Lakes region and the States adjoining Canada to the East.

In Alaska, white spruce is typically a tree of the interior rather than of the coastal region, although it extends to tidewater in a few places. It is found in forests of the woodland type, principally along the valley floors of the great rivers, and is by far the most important species of the interior.

White spruce is rarely more than 60 to 70 feet in height, and has a trunk of not more than 2 feet in diameter. The trees selected for test from near Matanuska averaged 56 feet in height and 97 years of age, the age ranging from 83 to 113 years. The diameter at the stump was 12 to 15 inches.

SUPPLY

It is estimated that white spruce comprises about 11 per cent of the 6,260,000,000 board feet of timber in the Chugach National Forest of Alaska or about 700,000,000 board feet. It represents a much larger percentage of the saw-timber stand of the interior.

PRODUCTION

The bulk of timber cut in the interior of Alaska is for firewood; probably several times as much is used each year for fuel as for lumber. Several small sawmills operate in the interior and spruce has been sawed for many years for local purposes. Thus white spruce has contributed greatly to the economic development of the country and will continue to do so, but as lumber for export it can not be regarded as important. In the United States proper the production of spruce saw timber of all species was one-half billion board feet in 1928, of which perhaps one-third was the white spruce. Large quantities are of course used in addition as pulpwood in the United States.

PROPERTIES

The wood of white spruce is moderately light in weight, weak in bending and compression, moderately limber, moderately soft, moderately low in shock resistance, and has a large shrinkage. It is ranked as easy to kiln dry, good in ability to stay in place, easy to work, low in nail-holding ability, very easy to glue and very low in decay resistance.

PRINCIPAL USES

The chief local uses of white spruce lumber in Alaska have been for flume and sluice boxes, boats, and building construction. White spruce is also used for certain airplane parts, sounding boards, organ pipes, ladders, joinery, boxes, and crates. It is one of the principal species for pulp and paper.

STUDIES OF MECHANICAL PROPERTIES

NATURE OF STUDIES

Three distinct types of studies have been made by the Forest Service on the mechanical properties of Alaska woods, as follows: (1) Standard tests on small, clear specimens of eight species, comprising Alaska white birch, Alaska cedar, western red cedar, mountain hemlock, western hemlock, balsam poplar, Sitka spruce, and white spruce; (2) tests on full-sized sawed structural timbers (containing defects) of Sitka spruce and western hemlock; and (3) tests on full-sized round mine timbers of Alaska white birch, western hemlock, Sitka spruce, and white spruce.

In considering the mechanical properties of woods grown in Alaska in connection with utilization requirements, three questions present themselves: (1) What are the strength properties of the species found in Alaska? (2) How do the properties of Alaska-grown timber compare with those of the same and other species grown elsewhere? (3) In using wood from Alaska for structural purposes, what working stresses are permissible?

The results of the several strength studies together with other data available furnish a basis for obtaining definite answers to these pertinent questions.

STANDARD TESTS OF SMALL, CLEAR SPECIMENS

SELECTION OF MATERIAL

The material used for determining the average properties of a wood from any one locality consisted of logs 5 feet or 9 feet in length taken from each of five or more representative trees, the upper part of the section usually being 16 feet above the stump. The Alaska species for test in the form of small, clear specimens were obtained from eight locations all of which were less than 400 feet above sea level.

The material collected in the Chugach National Forest near the Alaska Railroad was transported by train to Seward, Alaska, and thence by steamship to Seattle, Wash. The logs from the Tongass National Forest were rafted to Ketchikan, Alaska, for boat shipment to Seattle. The tests were made at the Forest Products Laboratory, Madison, Wis. (Pl. 8, A.)

CHARACTER OF TESTS

The standard tests, such as were made on small, clear specimens of Alaska woods as well as for similar studies of other species, serve as a basis for comparing and substituting species, promoting the use of

unknown and little-used woods, aiding in the determination of safe working stresses for design, determining the influence on strength of such factors as locality of growth, position in tree, rate of growth, and seasoning, grouping of species into utility classes for individual uses, such as boxes and ladders, developing specific gravity-strength laws, comparing virgin-growth and second-growth timber, determining the effect of growth conditions on properties, and studying the variability of wood.

The tests were made in accordance with the general plan used in testing woods from other parts of the United States (*2*), and, in general, similar to that now in use in Canada, England, New Zealand, India, and South Africa. The tests included both green and air-dried material. The air seasoning was accomplished by open piling the stock in a covered shed, open at the sides to permit circulation. The specimens (pl. 8, B) were 2 by 2 inches in cross section, except the specimens used for radial and tangential shrinkage, which were based on width measurements of pieces 1 inch thick, 4 inches wide, and 1 inch along the grain (pl. 8, C). Bending specimens were 30 inches long; others were shorter, depending on the kind of test. The results obtained on Alaska woods are consequently directly comparable with those of previous tests as reported in United States Department of Agriculture Bulletin 556 (*17*).

EXPLANATION OF TABLES 2, 3, AND 4

Table 2 presents the average test results of the Alaska woods for each locality from which specimens were obtained. In a few cases this permits comparing material from two sections of Alaska. Table 3 presents similar data on some of the same species grown in other parts of the United States, and thus, in conjunction with Table 2, affords a basis for comparing the strength of Alaska-grown wood with that of the same species from other regions.

TABLE 2.—*Average mechanical properties, by localities, of woods from Alaska*

[Based on tests of small, [1] clear specimens in the green and air-dry condition [2]]

Common and botanical name	Place of growth in Alaska of material tested	Trees tested	Rings per inch	Summer wood	Moisture content	Specific gravity oven dry, based on—		Weight per cubic foot	Shrinkage from green to oven-dry condition, based on dimensions when green			Static bending		
						Volume when green or at 12 per cent moisture	Volume when oven dry		Volumetric	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Number	*Number*	*Per cent*	*Per cent*			*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Birch, Alaska white (Betula neoalaskana):														
Green	Anchorage	10	29		58	0.49	0.59	48	16.7	6.5	9.9	3,800	7,100	1,350
Seasoned	do				12	.55		38				7,800	13,800	1,900
Cedar, Alaska (Chamaecyparis nootkatensis):														
Green	Ketchikan	3	23		35	.44	.51	37	11.4	4.2	7.7	4,100	6,900	1,420
Seasoned	do				12	.47		33				8,200	13,200	1,700
Cedar, western red (Thuja plicata):														
Green	do	5	18		34	.31	.34	26	7.0	2.2	4.6	3,000	4,900	850
Seasoned	do				12	.33		23				5,700	8,000	1,040
Hemlock, mountain (Tsuga mertensiana):														
Green	Girdwood	5	29		54	.45	.53	43	11.9	4.4	7.6	4,100	7,200	1,220
Seasoned	do				12	.50		35				8,500	12,600	1,520
Hemlock, western (Tsuga heterophylla):														
Green	Cordova	5	21		79	.36	.42	40	11.3	3.9	7.9	3,000	5,600	1,120
Seasoned	do				12	.40		28				6,000	9,200	1,380
Green	Ketchikan	6	21		66	.41	.47	42	12.4	4.5	7.8	3,800	6,600	1,320
Seasoned	do				12	.44		31				7,800	11,600	1,620
Poplar, balsam (Populus balsamifera):														
Green	Girdwood	5			104	.30	.36	38	13.0	4.0	8.7	2,100	3,700	700
Seasoned	do				12	.34		24				4,600	6,800	1,190
Spruce, Sitka (Picea sitchensis):														
Green	do	5	23		39	.39	.46	34	11.4	4.4	7.6	3,400	5,800	1,140
Seasoned	do				12	.42		29				6,800	11,300	1,620
Green	Ketchikan	5	17		39	.38	.43	33	11.6	4.0	7.7	3,300	5,900	1,300
Seasoned	do				12	.42		29				7,000	10,700	1,580
Spruce, white (Picea glauca):														
Green	Matanuska	5	22		50	.39	.46	36	12.6	5.8	9.1	3,200	5,700	1,150
Seasoned	do				12	.43		30				6,700	10,600	1,400

Common and botanical name	Place of growth in Alaska of material tested	Static bending		Impact bending			Compression parallel to grain		Compression perpendicular to grain, fiber stress at elastic limit	Shearing strength parallel to grain	Tension perpendicular to grain	Hardness (load required to embed a 0.444-inch ball to one-half its diameter)	
		Work in bending—		Fiber stress at elastic limit	Work in bending to elastic limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at elastic limit	Maximum crushing strength				End	Side
		To elastic limit	To maximum load										
1	2	16	17	18	19	20	21	22	23	24	25	26	27
		In.-lbs. per cu. in.	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*In.-lbs. per cu. in.*	*Ins.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs.*	*Lbs.*
Birch, Alaska white (Betula neoalaskana):													
Green	Anchorage	0.60	11.6	9,800	3.7	37	1,970	3,030	430	920	200	550	560
Seasoned	do	1.87	13.8	13,800	4.8	40	4,900	7,510	830	1,420	670	860	840
Cedar, Alaska (Chamaecyparis nootkatensis):													
Green	Ketchikan	.77	8.8	9,900	3.3	27	2,800	3,330	470	880	430	570	500
Seasoned	do	2.12	13.0	12,500	4.1	29	6,100	7,520	910	1,380	370	950	690
Cedar, western red (Thuja plicata):													
Green	do	.62	4.9	6,600	2.5	17	2,130	2,560	380	690	280	430	290
Seasoned	do	1.80	5.6	8,100	3.4	19	4,060	4,990	700	870	300	720	390
Hemlock, mountain (Tsuga mertensiana):													
Green	Girdwood	.80	9.8	9,400	3.4	28	2,480	3,410	540	940	300	610	540
Seasoned	do	2.70	8.4	12,900	5.0	29	5,730	7,790	1,060	1,290	300	1,260	860
Hemlock, western (Tsuga heterophylla):													
Green	Cordova	.48	7.0	7,700	2.8	21	2,220	2,780	390	770	330	450	380
Seasoned	do	1.52	7.4	11,800	5.2	23	4,510	5,700	620	1,160	360	920	530
Green	Ketchikan	.62	7.3	8,500	3.0	26	2,680	3,240	460	840	330	560	480
Seasoned	do	2.10	8.8	13,600	6.1	31	5,900	7,020	780	1,320	340	1,040	660
Poplar, balsam (Populus balsamifera):													
Green	Girdwood	.37	4.2	5,700	2.2	13	1,080	1,660	180	490	150	210	200
Seasoned	do	1.04	4.4	8,400	2.6	14	2,750	4,230	350	750	380	360	290
Spruce, Sitka (Picea sitchensis):													
Green	do	.56	6.7	8,400	3.1	23	2,240	2,710	420	760	330	400	330
Seasoned	do	1.59	10.1	10,800	3.8	21	4,700	6,340	690	1,110	340	650	520
Green	Ketchikan	.51	6.3	8,300	2.9	23	2,290	2,810	380	780	300	460	400
Seasoned	do	1.76	9.6	10,000	3.3	29	4,800	5,920	720	1,060	420	950	580
Spruce, white (Picea glauca):													
Green	Matanuska	.51	5.8	7,600	2.7	24	2,150	2,720	350	710	230	370	350
Seasoned	do	1.83	8.0	11,100	4.2	22	4,750	6,230	740	1,310	390	640	500

[1] Test specimens 2 by 2 inches in section. Bending specimens 30 inches long; others shorter, depending on kind of test.

[2] The values in the first line for each species are from tests of green material; those in the second line are from tests of seasoned material adjusted to an average air-dry condition of 12 per cent moisture.

TABLE 3.—*Average mechanical properties, by localities, of woods from the United States proper whose range of growth includes Alaska*

[Based on tests of small,[1] clear specimens in the green and air-dry condition [2]]

Common and botanical name	Place of growth of material tested	Trees tested	Rings per inch	Summer wood	Moisture content	Specific gravity oven-dry, based on—		Weight per cubic foot	Shrinkage from green to oven-dry condition, based on dimensions when green			Static bending		
						Volume when green or at 12 per cent moisture	Volume when oven dry		Volumetric	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Number	*Number*	*Per cent*	*Per cent*			*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Cedar, Alaska (Chamaecyparis nootkatensis):														
Green	Lane County, Oreg.	5	31		40	0.40	0.44	35	7.9	1.9	5.0	3,600	6,200	960
Seasoned	do				12	.42		29				6,700	10,100	1,270
Cedar western red (Thuja plicata):														
Green	Missoula County, Mont.	5	21	42	33	.29	.33	24	7.6	2.5	4.6	2,900	4,800	890
Seasoned	do				12	.31		22				4,600	7,000	1,120
Green	Snohomish County Wash.	5	20	31	45	.33	.36	30	8.6	2.5	5.6	3,600	5,700	1,020
Seasoned	do				12	.35		24				5,700	8,400	1,220
Hemlock, mountain (Tsuga mertensiana):														
Green	Montana	5	23	45	70	.42	.48	45	10.8	4.4	7.1	3,500	6,000	940
Seasoned	do				12	.45		31				6,300	9,900	1,130
Hemlock, western (Tsuga heterophylla):														
Green	Chehalis County, Wash.	5	10	27	71	.38	.43	41	11.6	4.5	7.9	3,400	6,100	1,190
Seasoned	do				12	.40		28				6,100	9,000	1,420
Green	Oregon	2	12	40	92	.38	.44	46	11.8			3,800	6,200	1,270
Seasoned	do				12	.41		29				7,600	10,100	1,540
Poplar, balsam (Populus balsamifera):														
Green	Bennington County, Vt.	5	5		121	.30	.33	42	8.0	2.0	5.4	2,100	4,000	800
Seasoned	do				12	.32		22				3,900	6,800	1,020
Spruce, Sitka (Picea sitchensis):														
Green	Chehalis County, Wash.	5	9	24	53	.34	.37	32	11.2	4.5	7.4	3,000	5,500	1,180
Seasoned	do				12	.37		26				6,200	9,800	1,520
Green	Clatsop County, Oreg.	4	15		45	.34	.38	31	10.7	4.0	7.0	3,200	4,900	1,090
Seasoned	do				12	.38		27				6,300	8,500	1,370
Green	Oregon	3	14	47	36	.38	.44	32	12.8			3,700	6,000	1,460
Seasoned	do				12	.42		29				7,700	11,400	1,740
Green	do	3	10	41	34	.37	.42	31	11.2	4.5	7.9	3,600	5,900	1,310
Seasoned	do				12	.38		27				6,200	9,300	1,560
Spruce, white (Picea glauca):														
Green	Coos County, N. H.	5	11	22	52	.35		33				3,300	5,700	1,060
Seasoned	do				12	.37		26				6,000	9,300	1,360
Green	Rusk County, Wis.	5	17	29	48	.38	.43	35	14.8	3.7	7.3	3,400	5,400	990
Seasoned	do				12	.41		29				6,200	9,000	1,500

Common and botanical name	Place of growth of material tested	Static bending		Impact bending			Compression parallel to grain		Compression perpendicular to grain, fiber stress at elastic limit	Shearing strength parallel to grain	Tension perpendicular to grain	Hardness (load required to embed a 0.444-inch ball to one-half its diameter)	
		Work in bending—		Fiber stress at elastic limit	Work in bending to elastic limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at elastic limit	Maximum crushing strength				End	Side
		To elastic limit	To maximum load										
1	2	16	17	18	19	20	21	22	23	24	25	26	27
		In.-lbs. per cu. in.	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*In.-lbs. per cu. in.*	*Ins.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs.*	*Lbs.*
Cedar, Alaska (Chamaecyparis nootkatensis):													
Green	Lane County, Oreg.	0.77	9.5	8,600	3.2	27	2,390	2,880	410	820	260	520	410
Seasoned	do	2.10	8.8	12,200	5.8	28	5,330	5,800	720	1,000	360	700	520
Cedar, western red (Thuja plicata):													
Green	Missoula County, Mont.	.54	4.5	6,400	2.0	16	2,300	2,630	280	700	220	390	250
Seasoned	do	1.08	4.8	9,000	3.3	11	4,170	4,920	460	810	190	550	300
Green	Snohomish County, Wash.	.74	5.6	7,800	2.9	18	2,690	3,050	350	740	200	460	270
Seasoned	do	1.54	7.2	8,800	3.0	20	4,720	5,450	690	920	.....	740	380
Hemlock, mountain (Tsuga mertensiana):													
Green	Montana	.78	9.4	8,800	3.6	36	2,590	2,890	400	880	360	580	460
Seasoned	do	2.09	9.2	13,800	6.7	36	3,890	6,090	1,030	1,170	340	1,080	640
Hemlock, western (Tsuga heterophylla):													
Green	Chehalis County, Wash.	.58	6.0	7,800	2.4	20	2,290	2,890	350	810	260	540	430
Seasoned	do	1.57	6.1	11,100	4.5	24	5,260	5,760	620	1,040	190	840	550
Green	Oregon	.62	6.6	9,000	3.1	20	.....	3,040	320	800	300	510	400
Seasoned	do	2.11	7.4	13,300	5.7	24	.....	6,080	640	1,080	370	830	500
Poplar, balsam (Populus balsamifera):													
Green	Bennington County, Vt.	.32	4.2	6,200	2.3	18	1,200	1,720	160	520	180	260	250
Seasoned	do	.92	5.7	7,700	2.8	14	2,920	3,810	390	840	320	400	320
Spruce, Sitka (Picea sitchensis):													
Green	Chehalis County, Wash.	.44	6.4	7,900	2.5	29	2,260	2,600	330	780	230	430	370
Seasoned	do	1.38	9.5	12,500	4.5	26	4,390	5,000	800	1,110	440	700	500

[1] Test specimens 2 by 2 inches in section. Bending specimens 30 inches long; others shorter, depending on kind of test.

[2] The values in the first line for each species are from tests of green material; those in the second line are from tests of seasoned material adjusted to an average air-dry condition of 12 per cent moisture.

TABLE 3.—*Average mechanical properties, by localities, of woods from the United States proper whose range of growth includes Alaska*—Continued

Common and botanical name	Place of growth in Alaska of material tested	Static bending		Impact bending			Compression parallel to grain		Compression perpendicular to grain, fiber stress at elastic limit	Shearing strength parallel to grain	Tension perpendicular to grain	Hardness (load required to embed a 0.444-inch ball to one-half its diameter)	
		Work in bending—		Fiber stress at elastic limit	Work in bending to elastic limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at elastic limit	Maximum crushing strength				End	Side
		To elastic limit	To maximum load										
1	2	16	17	18	19	20	21	22	23	24	25	26	27
		In.-lbs. per cu. in.	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*In.-lbs. per cu. in.*	*Ins.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs.*	*Lbs.*
Spruce, Sitka (Picea sitchensis)—Continued.													
Green	Clatsop County, Oreg.	0.53	5.4	7,800	2.7	20	1,920	2,180	220	700	170	350	280
Seasoned	do	1.52	7.4	10,000	3.7	21	3,750	4,730	580	1,260	440	690	440
Green	Oregon	.58	6.2	9,600	3.5	24		2,840	360	780	160	480	350
Seasoned	do	1.93	11.4	13,800	5.7	28		5,850	750	1,280	370	810	520
Green	do	.59	6.5	9,300	3.9	23		2,930	350	750	300	480	350
Seasoned	do	1.41	8.1	12,000	4.7	24		5,830	680	1,110	340	780	450
Spruce, white (Picea glauca):													
Green	Coos County, N. H.	.61	6.7				1,990	2,440	280	680		220	240
Seasoned	do	1.47	8.0	9,700	3.5	20	4,230	5,020	460	1,130	350	540	440
Green	Rusk County, Wis.	.69	5.4	6,800	2.0	20	2,140	2,550	270	690	200	290	280
Seasoned	do	1.67	6.6				3,660	5,320	540	770		700	530

TABLE 4.—*Average mechanical properties of eighteen species of wood* [1]

[Based on tests of small, [2] clear specimens in the green and air-dry condition [3]]

Common and botanical name	Place of growth of material tested	Trees tested	Rings per inch	Summer wood	Moisture content	Specific gravity, oven-dry, based on—		Weight per cubic foot	Shrinkage from green to oven-dry condition, based on dimensions when green			Static bending		
						Volume when green or at 12 per cent moisture	Volume when oven dry		Volumetric	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Number	*Number*	*Per cent*	*Per cent*			*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Alder, red (Alnus rubra):														
Green	Washington	6	11		98	0.37	0.43	46	12.6	4.4	7.3	3,800	6,500	1,170
Seasoned	do				12	.41		28				7,100	10,000	1,380
Birch, Alaska white (Betula neoalaskana):														
Green	Alaska	10	29		58	.49	.59	48	16.7	6.5	9.9	3,800	7,100	1,350
Seasoned	do				12	.55		38				7,800	13,800	1,900
Birch, gray (Betula populifolia):														
Green	New Hampshire	5			63	.45	.55	46	14.7	5.2		1,800	4,900	400
Seasoned	do				12	.51		35				5,400	9,800	1,130
Birch, yellow (Betula lutea):														
Green	Wisconsin, Vermont, Pennsylvania.	17	16	26	67	.55	.66	57	16.7	7.2	9.2	4,200	8,300	1,500
Seasoned	do				12	.62		43				10,000	16,600	2,010
Cedar, Alaska (Chamaecyparis nootkatensis):														
Green	Alaska, Oregon	8	28		38	.42	.46	36	9.2	2.8	6.0	3,800	6,400	1,140
Seasoned	do				12	.44		30				7,300	11,300	1,430
Cedar, northern white (Thuja occidentalis):														
Green	Wisconsin	5	23	36	55	.29	.32	28	7.0	2.1	4.7	2,600	4,200	640
Seasoned	do				12	.31		22				4,900	6,500	800

[1] The values given in this table comprise the average of all comparable data on each species regardless of region where grown. Any differences of these values from those given in U. S. Dept. Agr. Bul. 556, Mechanical Properties of Woods Grown in the United States (17), for the same species are due (1) to additional tests made since that bulletin was published (1917) and (2) to the fact that the values for air-dry material are herein reduced to a uniform moisture basis to make the results directly comparable.

[2] Test specimens 2 by 2 inches in section. Bending specimens 30 inches long; others shorter, depending on kind of test.

[3] The values in the first line for each species are from tests of green material; those in the second line are from tests of seasoned material adjusted to an average air-dry condition of 12 per cent moisture.

TABLE 4.—*Average mechanical properties of eighteen species of wood*—Continued

Common and botanical name	Place of growth in Alaska of material tested	Trees tested	Rings per inch	Summer wood	Moisture content	Specific gravity oven dry, based on—		Weight per cubic foot	Shrinkage from green to oven-dry condition, based on dimensions when green			Static bending		
						Volume when green or at 12 per cent moisture	Volume when oven dry		Volumetric	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Number	*Number*	*Per cent*	*Per cent*			*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Cedar, western red (Thuja plicata):														
Green	Alaska, Montana, Washington.	15	19	36	37	0.31	0.34	27	7.7	2.4	5.0	3,200	5,100	920
Seasoned	do				12	.33		23				5,400	7,800	1,120
Cottonwood, northern black (Populus trichocarpa hastata):														
Green	Washington	5	6		132	.32	.37	46	12.4	3.6	8.6	2,900	4,800	1,070
Seasoned	do				12	.35		24				5,400	8,500	1,260
Douglas fir (coast type) (Pseudotsuga taxifolia):														
Green	Washington, Oregon, California.	34	14	36	36	.45	.51	38	11.8	5.0	7.8	4,800	7,600	1,550
Seasoned	do				12	.48		34				8,200	11,900	1,930
Douglas fir (mountain type) (Pseudotsuga taxifolia):														
Green	Montana, Wyoming	10	22	27	38	.40	.45	35	10.6	3.6	6.2	3,600	6,400	1,180
Seasoned	do				12	.43		30				6,300	9,600	1,410
Hemlock, eastern (Tsuga canadensis):														
Green	Wisconsin, Tennessee, New Hampshire, Vermont.	20	17	34	111	.38	.43	50	9.7	3.0	6.8	3,800	6,400	1,070
Seasoned	do				12	.40		28				6,100	9,000	1,210
Hemlock, mountain (Tsuga mertensiana):														
Green	Alaska, Montana	10	26	45	62	.43	.51	44	11.4	4.4	7.4	3,800	6,600	1,080
Seasoned	do				12	.47		33				7,400	11,200	1,330
Hemlock, western (Tsuga heterophylla):														
Green	Alaska, Washington, Oregon.	18	17	31	74	.38	.44	42	11.9	4.3	7.9	3,400	6,100	1,220
Seasoned	do				12	.42		29				6,800	10,000	1,490

Maple, bigleaf (Acer macrophyllum):														
Green	Washington	5	12		72	.44	.51	47	11.6	3.7	7.1	4,400	7,400	1,090
Seasoned	do				12	.48		34				6,700	10,800	1,479
Pine, western white (Pinus monticola):														
Green	Idaho, Montana	14	20	33	54	.36	.42	35	11.8	4.1	7.4	3,400	5,200	1,170
Seasoned	do				12	.38		27				6,300	9,600	1,520
Poplar, balsam (Populus balsamifera):														
Green	Alaska, Vermont	10	7		112	.30	.35	40	10.5	3.0	7.1	2,100	3,900	750
Seasoned	do				12	.33		23				4,200	6,800	1,110
Spruce, Sitka (Picea sitchensis):														
Green	Alaska, Washington, Oregon.	25	15	35	42	.37	.42	32	11.5	4.3	7.5	3,300	5,700	1,230
Seasoned	do				12	.40		28				6,700	10,200	1,570
Spruce, white (Picea glauca):														
Green	Alaska, Wisconsin, New Hampshire.	15	17	26	50	.37	.45	35	13.7	4.7	8.2	3,300	5,600	1,070
Seasoned	do				12	.40		28				6,300	9,600	1,420

TABLE 4.—*Average mechanical properties of eighteen species of wood*—Continued

Common and botanical name	Place of growth of material tested	Static bending—Continued		Impact bending			Compression parallel to grain		Compression perpendicular to grain, fiber stress at elastic limit	Shearing strength parallel to grain	Tension perpendicular to grain	Hardness (load required to embed a 0.444-inch ball to one-half its diameter)	
		Work in bending—		Fiber stress at elastic limit	Work in bending to elastic limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at elastic limit	Maximum crushing strength				End	Side
		To elastic limit	To maximum load										
1	2	16	17	18	19	20	21	22	23	24	25	26	27
		In.-lbs. per cu. in.	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*In.-lbs. per cu. in.*	*Inches*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs.*	*Lbs.*
Alder, red (Alnus rubra):													
Green	Washington	0.70	8.0	8,000	2.6	22	2,650	2,960	310	770	390	550	440
Seasoned	do	1.90	8.4	11,700	4.9	20	4,660	5,960	550	1,100	420	980	600
Birch, Alaska white (Betula neoalaskana):													
Green	Alaska	.60	11.6	9,800	3.7	37	1,970	3,030	430	920	200	550	560
Seasoned	do	1.87	13.8	13,800	4.8	40	4,900	7,510	830	1,420	670	860	840
Birch, gray (Betula populifolia):													
Green	New Hampshire	.47	13.9	7,400	2.6	59	1,000	1,860	300	------	------	440	480
Seasoned	do	1.44	10.8	10,400	3.5	35	3,050	4,880	950	------	------	690	770
Birch, yellow (Betula lutea):													
Green	Wisconsin, Vermont, Pennsylvania.	.70	16.1	11,500	4.4	48	2,530	3,380	530	1,110	430	810	780
Seasoned	do	2.87	20.8	17,200	7.2	55	5,930	8,110	1,180	1,900	920	1,480	1,260
Cedar, Alaska (Chamaecyparis nootkatensis):													
Green	Alaska, Oregon	.77	9.2	9,100	3.2	27	2,540	3,050	430	840	330	540	440
Seasoned	do	2.11	10.4	12,300	5.2	29	5,620	6,440	790	1,140	360	800	590
Cedar, northern white (Thuja occidentalis):													
Green	Wisconsin	.60	5.7	5,300	2.0	15	1,420	1,990	290	620	240	320	230
Seasoned	do	1.73	4.8	7,100	2.8	12	2,730	3,980	380	890	240	450	320
Cedar, western red (Thuja plicata)													
Green	Alaska, Montana, Washington.	.63	5.0	6,900	2.5	17	2,370	2,750	340	710	250	430	270
Seasoned	do	1.47	5.9	8,600	3.2	17	4,320	5,120	620	870	240	670	360
Cottonwood, northern black (Populus trichocarpa hastata):													
Green	Washington	.44	5.0	6,800	2.2	20	1,770	2,160	200	600	270	280	250
Seasoned	do	1.28	6.7	9,900	3.8	22	3,680	4,510	380	1,010	330	550	350

Douglas fir (coast type) (Pseudotsuga taxifolia):													
Green	Washington, Oregon, California.	.85	6.8	9,800	3.2	24	3,430	3,890	510	930	250	510	480
Seasoned	do	2.02	8.7	12,900	4.6	30	6,870	7,590	920	1,140	310	770	670
Douglas fir (mountain type) (Pseudotsuga taxifolia):													
Green	Montana, Wyoming	.65	6.8	9,100	3.0	20	2,520	3,000	450	880	350	450	400
Seasoned	do	1.61	6.4	12,200	4.8	26	4,720	6,140	830	1,040	320	740	630
Hemlock eastern (Tsuga canadensis):													
Green	Wisconsin, Tennessee, New Hampshire, Vermont.	.76	6.7	7,900	2.9	21	2,480	3,080	440	850	230	500	400
Seasoned	do	1.81	6.8	10,700	4.8	20	3,960	5,490	820	1,070	220	820	510
Hemlock, mountain (Tsuga mertensiana):													
Green	Alaska, Montana	.79	9.6	9,100	3.5	32	2,540	3,150	470	910	330	600	500
Seasoned	do	2.40	8.8	13,400	5.8	32	4,810	6,940	1,040	1,230	320	1,170	750
Hemlock, western (Tsuga heterophylla):													
Green	Alaska, Washington, Oregon.	.57	6.8	8,100	2.8	22	2,410	2,990	390	810	310	520	430
Seasoned	do	1.80	7.5	12,400	5.4	26	5,210	6,200	670	1,160	310	940	580
Maple, bigleaf (Acer macrophyllum):													
Green	Washington	1.02	8.7	8,500	2.8	23	2,380	3,240	550	1,110	600	760	620
Seasoned	do	1.68	7.8			28	5,200	6,[illegible]	940	1,770	540	1,360	850
Pine, western white (Pinus monticola):													
Green	Idaho, Montana	.56	5.0	7,600	2.6	19	2,390	2,650	290	640	260	310	310
Seasoned	do	1.51	8.9	12,000	4.5	23	4,910	5,720	540	940	280	440	380
Poplar, balsam (Populus balsami era):													
Green	Alaska, Vermont	.35	4.2	6,000	2.2	16	1,140	1,690	170	500	160	240	230
Seasoned	do	.98	5.0	8,000	2.7	14	2,840	4,020	370	800	350	380	300
Spruce, Sitka (Picea sitchensis):													
Green	Alaska, Washington, Oregon.	.53	6.3	8,400	3.0	24	2,190	2,670	340	760	250	430	350
Seasoned	do	1.61	9.4	11,400	4.1	25	4,460	5,590	710	1,140	400	760	510
Spruce, white (Picea glauca):													
Green	Alaska, Wisconsin, New Hampshire.	.60	6.0	7,200	2.4	22	2,090	2,570	290	690	210	300	290
Seasoned	do	1.66	7.5	10,400	3.8	21	4,230	5,520	580	1,070	370	630	490

Table 4 presents the average results of all comparable tests made by the Forest Products Laboratory on woods that grow in Alaska, and in addition, other data on well-known species. Previous studies by the laboratory have shown that the average results for material from all localities tested is a better criterion of the properties of material from any untested site than are the results of tests from seemingly similar sites, as appraised by the usually recorded characteristics. Table 4 represents the best estimate of the true average for each of the species, and accordingly affords the best basis for comparing the various species. These data are second only in importance to the grade of timber in determining safe working stresses for timber design.

The first line of figures for each species in Tables 2, 3, and 4 are the results of tests on green material; those in the second line are from tests of seasoned material adjusted to an average air-dry condition of 12 per cent moisture.

Column 1, Common and Botanical Names of Species

Many of the species have numerous common names, and not infrequently one common name is applied to several species. This leads to so much confusion that it is necessary to refer to a standard nomenclature. The common and botanical names used in the tables are those given in Check List of the Forest Trees of the United States, Their Names and Ranges (*18*).

Column 2, Place of Growth of Material Tested

In the second columns of Tables 2 and 3 are listed the locality in which the test specimens were grown; in the second column of Table 4 the States from which test material represented in the average figures was obtained.

Column 3, Number of Trees Tested

The number of trees from which test specimens were taken is given in the third column of Tables 2, 3, and 4. As previously mentioned, five is the usual number from a single locality.

Column 4, Number of Rings Per Inch

The number of rings per inch is an inverse measure of the rate of diameter growth. It is taken along a radial line on the end section of each specimen. One ring, consisting of a band of spring wood and a band of summer wood, is formed by each year's growth; consequently, few rings per inch indicate fast growth, and conversely.

Column 5, Summer Wood

The amount of summer wood is expressed as a percentage of the entire cross section. (See definition of summer wood, p. 75.) It is measured along a representative radial line. In some species the proportion of summer wood gives a fairly accurate estimate of the density; in others the contrast between spring wood and summer

wood is so indistinct that no measurement can be made. It is of no practical value except in species in which the relation to density has been worked out.

Column 6, Moisture Content

Moisture content is the weight of water contained in the wood, expressed as a percentage of the oven-dry weight of the wood.

The moisture content given for green material is the average for specimens taken from the pith to the circumference of the log, and hence represents a combination of the moisture as found in the heartwood and in the sapwood. In many species there is much more moisture in the sapwood than in the heartwood.

The moisture content of the air-dry material when tested varied somewhat among the different species. To facilitate comparison of strength properties, the test values were adjusted to conform to the uniform condition of 12 per cent moisture as indicated.

Columns 7 and 8, Specific Gravity

Specifiic gravity of wood is its weight divided by the weight of an equal volume of water.

Obviously, the weight of wood in a given volume changes with the shrinkage and swelling caused by changes in moisture. Consequently, specific gravity is an indefinite quantity unless the circumstances under which it is determined are specified. Each of the columns of specific gravity figures given in Tables 2, 3, and 4 is based on the weight of the wood when oven dry and on its volume when green or at a specified stage of drying.

Column 9, Weight Per Cubic Foot

The weight per cubic foot that is given in the first horizontal line of figures opposite each species in Tables 2, 3, and 4, is the weight per cubic foot of the wood (including moisture) as received at the Forest Products Laboratory, and because of the protection from seasoning in transit and pending test, it represents closely the weight of the wood as it comes from the living tree. The various species differ largely as to the wetness of the green wood. The weight per cubic foot that is given in the second horizontal line of figures opposite each species, is from tests of seasoned material adjusted to an average air-dry condition of 12 per cent moisture content.

Columns 10, 11, and 12, Shrinkage from Green to Oven-Dry Condition

When wood is dried below the fiber-saturation point,[5] shrinkage begins and continues until the moisture is all driven off. Shrinkage along the length of timber is small. Shrinkage in directions at right angles to the length is much greater.

All shrinkages given in Tables 2, 3, and 4 are expressed in percentages of the original or green dimensions, and are total shrinkages

[5] Green wood usually contains "absorbed" water within the cell walls and "free" water in the cell cavities. In drying, the free water from the cell cavities is the first to be evaporated. The fiber-saturation point is that point at which no water exists in the cell cavities of the timber, but at which the cell walls are still saturated. The fiber-saturation point varies with the species. The ordinary proportion of moisture at the fiber-saturation point is from 22 to 30 per cent of the dry weight of the wood.

from green to zero moisture. The specimens on which the data are based were air dried at room temperatures from the green condition and then oven dried to constant weight at 100° C. Shrinkage to an air-dry condition of about 12 per cent moisture is sometimes more and sometimes less than half the total shrinkage. Radial shrinkage is the measure of the change in width of a quarter-sawed or edge-grain board. Tangential shrinkage is the measure of the change in width of a flat-sawed board.

Columns 13, 14, 15, 16, and 17, Static Bending

In the static bending test a 2 by 2 by 30 inch beam is supported over a 28-inch span. Loading is applied to its center and at a constant rate of deflection until the beam fails. (Fig. 2.) Readings of load and deflection are taken simultaneously.

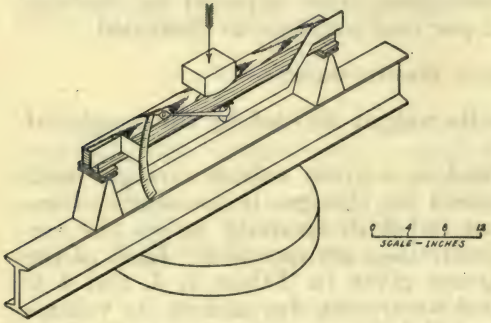


FIGURE 2.—Diagrammatic sketch of method of conducting static bending test

The values derived from this test are applicable to beams of any size by the use of a bending formula, except for the defects that occur in the larger sizes.

Fiber Stress at Elastic Limit

Fiber stress at elastic limit is the stress obtained in a timber by loading it to its elastic limit. It is the greatest stress the timber is capable of developing without a permanent deformation remaining upon complete removal of the load.

Modulus of Rupture

Modulus of rupture is the computed fiber stress in the outermost fibers of a beam at the maximum load and is a measure of the ability of a beam to support a slowly applied load for a very short time. The formula by which modulus of rupture is computed is the same as that for fiber stress at elastic limit, the maximum load being substituted for the elastic limit load. The assumptions on which this formula are based hold only up to the elastic limit, hence modulus of rupture is not a true fiber stress. It is, however, a universally accepted term, and the values are quite comparable for various species and sizes of timber. It is a definite quantity, and the personal factor does not enter to any great extent into obtaining it. It is consequently not so subject to error as the fiber stress at elastic limit, and for that reason is used more than any other value to represent the strength of wood. Modulus of rupture should always be considered in calculating the strength of beams to be used as stringers, floor joists, and the like.

Safe working stresses for carefully selected structural timbers, with all exceptionally light pieces excluded, subjected to bending in dry interior construction and where only small deflections are allowable are about one-fifth the modulus of rupture values given in Table

4 for green material. In some interior construction where beams may be allowed to sag somewhat without damage, the working stresses may be slightly increased. But for timbers used in bridges or other structures exposed to moisture, the working stress should be lower. However, beams can not be correctly designed on the basis of outer fiber stress in bending alone. Strength in longitudinal shear and bearing area must also be taken into account.

MODULUS OF ELASTICITY

The modulus of elasticity is a measure of the stiffness or rigidity of a material. In the case of a beam, modulus of elasticity is a measure of its resistance to deflection. The formula connecting modulus of elasticity, load, and deflection shows that the deflection under a given load varies inversely as the modulus of elasticity; that is, a beam with a high modulus deflects but little. Modulus of elasticity is of value in computing the deflections of joists, beams, and stringers, and in computing safe loads for long columns. The values given are derived from the static bending test, but are applicable to both beams and long columns.

WORK IN BENDING TO ELASTIC LIMIT

Work to elastic limit in static bending is a measure of the work that a beam is able to resist or the shock that it can absorb without being stressed beyond the elastic limit as determined under slowly applied loads.

WORK IN BENDING TO MAXIMUM LOAD

Work to maximum load in static bending represents the ability of the timber to absorb shock with some permanent deformation and with more or less injury to the timber. Work to maximum load is a measure of the combined strength and toughness of a material under bending stresses. Superiority in this quality is one characteristic which makes hickory better than ash, and oak better than longleaf pine, for such uses as handles and vehicle parts. Many species yield butt cuts that exceed upper cuts in combined strength and toughness, hickory showing this characteristic most markedly. The superiority of butt cuts of hickory to upper cuts for ax handles is well known to experienced woodsmen.

Columns 18, 19, and 20, Impact Bending

The impact bending test is made upon a beam 2 by 2 by 30 inches over a 28-inch span. A 50-pound hammer is dropped upon the stick at the center of the span, first from a height of 1 inch, next 2 inches, and so on up to 10 inches, then increasing 2 inches at a time until complete failure occurs. The deflections of the specimen are recorded on a revolving drum by a pointer attached to the hammer. The pointer also records the position the specimen assumes after the shock. Thus data are obtained for determining the various properties of the wood when subjected to shock.

FIBER STRESS AT ELASTIC LIMIT

Fiber stress at elastic limit is the greatest stress to which a timber may be subjected under impact loading and recover immediately. Fiber stress at elastic limit in impact is approximately double the fiber stress at elastic limit in static bending. This is an expression of the fact that a small beam, if suddenly strained, bends approximately twice as far to the elastic limit as when loaded slowly. (See also fiber stress at elastic limit, p. 73.)

WORK IN BENDING TO ELASTIC LIMIT

Work in bending to the elastic limit in impact is a measure of the ability of a timber to absorb shock and recover therefrom immediately and without injury. The values apply only to resistance to falling bodies or to other conditions in which the stress is applied and relieved in one twenty-fifth of a second or less. It represents a quality important in tool handles and in athletic goods, such as baseball bats.

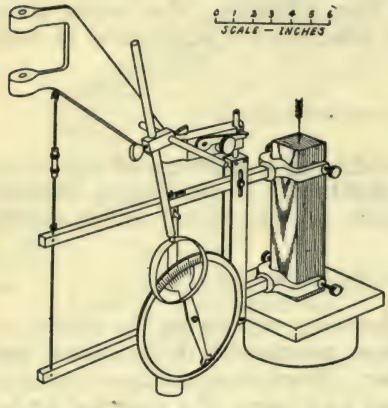


FIGURE 3.—Diagrammatic sketch of compressometer and method of conducting compression-parallel-to-grain test

COLUMNS 21 AND 22 COMPRESSION PARALLEL TO GRAIN

Height of drop is the maximum or the last drop of the hammer that causes failure. It represents a quality important in articles that are occasionally stressed under a shock beyond their elastic limit, such as handles and vehicle and implement parts.

COLUMNS 21 AND 22 COMPRESSION PARALLEL TO GRAIN

In the compression parallel to grain test a 2 by 2 by 8 inch block is compressed in the direction of its length. (Fig. 3.) Deformation is measured between two collars attached 6 inches apart to the specimen.

FIBER STRESS AT ELASTIC LIMIT

Fiber stress at elastic limit in compression parallel to the grain is little used because it is usually more convenient to use maximum crushing strength, which is less variable and easier to obtain. Fiber stress at elastic limit is important in the derivation of safe working stresses for structural timber. (See also fiber stress at elastic limit, p. 73.)

MAXIMUM CRUSHING STRENGTH

The maximum crushing strength is the maximum ability of a short block to sustain a slowly applied end load. It is obtained by dividing the maximum load obtained in the test by the area of cross section of the block. This property is important in estimating the strength of short columns and those of intermediate length.

Tests of the crushing strength, because of their simplicity, are frequently the only tests used in studying the effect of various influences or processes on strength. Crushing strength is not necessarily representative of the other strength properties.

A safe working stress for carefully selected structural timbers used as short columns and in dry interior construction, provided all exceptionally light pieces are excluded, is about one-third to one-fourth the crushing strength as given in Table 4 for tests on green materials. If the column is longer than about 10 times its least diameter, a formula should be used that will take care of the increased stress which would be caused by eccentric loading or by the bending of the column (*14*).

Column 23, Compression Perpendicular to Grain

In the compression-perpendicular-to-grain test, a block 2 by 2 inches in cross section and 6 inches long is laid upon its side and pressure applied to it through an iron plate 2 inches wide laid across the center of the piece and at right angles to its length. (Fig. 4.) Hence but one-third of the surface is directly subjected to compression.

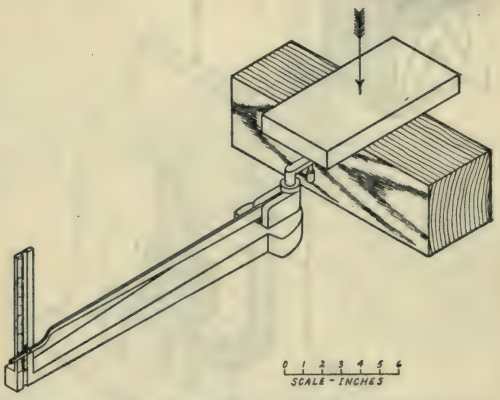


Figure 4.—Diagrammatic sketch of method of conducting compression-perpendicular-to-grain test

The only strength value obtained in this test is the fiber stress at elastic limit. It represents the maximum stress across the grain which can be applied to the timber without injury. It is important in computing the bearing area for beams, stringers, and joists, and in comparing species for railroad ties.

Two-thirds of the fiber stress at elastic limit, as given in Table 4 for tests on green material, may be used as a safe stress in dry interior construction.

Column 24, Shearing Strength Parallel to Grain

The shearing test is made by applying force to a 2 by 2 inch lip projecting from the side of a block. (Fig. 5.) The shearing stress is the maximum force required to shear off the projection divided by the area of the plane of failure.

Shearing strength parallel to the grain is a measure of the ability of timber to resist slipping of one part upon another along the grain. Shearing stress is produced in most uses of timber. It is most important in beams, where it is known as horizontal shear—the stress tending to cause the upper half of the beam to slide upon the lower. It is also important in the design of various kinds of timber joints.

Only about one-eighth of the values given in the table for green material (Table 4) should be used as allowable stress in horizontal shear in beams. For small details, in timber unaffected by shakes or checks, the allowable stress may be taken as 50 per cent greater.

Column 25, Tension Perpendicular to Grain

The tension-perpendicular-to-grain tests are made on specimens 2 inches square and 2½ inches long, the tension area being 1 by 2 inches. The tension force is applied perpendicular to the grain. (Fig. 6.) The values are of use in estimating the resistance of timber to the splitting actions of bolts and other fastenings. A factor of 5 should be applied to the values in Table 4 to get the allowable stress for design; that is, one-fifth of the values given in the table.

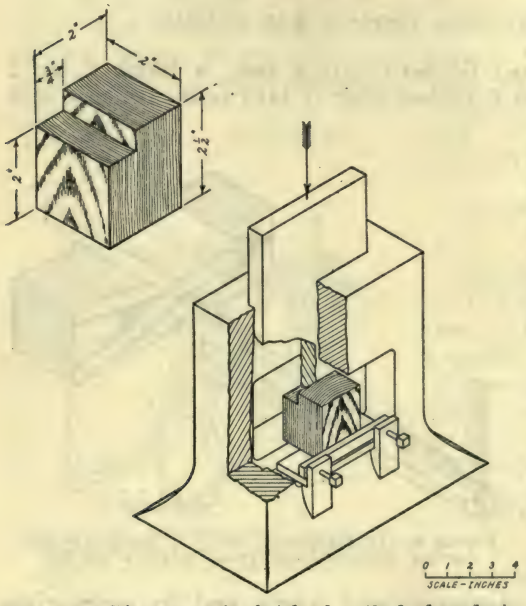


FIGURE 5.—Diagrammatic sketch of method of conducting shear-parallel-to-grain test, with details of test specimen

Columns 26 and 27 Hardness

Hardness is tested by measuring the load required to embed a 0.444-inch ball to one-half its diameter in the wood. (Fig. 7.) The hardness test is applied to end, radial, and tangential surfaces of the timber. There is no significant difference between radial and tangential hardness and they are averaged and tabulated as "side hardness." End hardness is usually greater than side hardness. The quality represented by the figures is important in woods for railroad ties, furniture, flooring, and the like.

PRECAUTIONS TO BE OBSERVED IN THE USE OF DATA

The test results obtained in studying the properties of clear wood are dependent on the size and form of test specimens, the rate of loading, and other factors entering into methods of testing, and in seasoned material on the moisture content. Care should accordingly be used in attempting to compare the data with that from other sources in which a different test procedure has been used.

The figures of Tables 2, 3, and 4 are primarily for the comparison of species in the form of clear lumber. For comparing structural timbers in which the defects are limited with reference to their effect

on strength, the allowable working stresses presented in Table 19 are recommended.

VARIATION IN STRENGTH OF WOOD

Variability is a characteristic of all materials, although there may be wide differences in its magnitude. The living tree is subjected to numerous influences that have a bearing on the wood produced, and it is not surprising as a result that even the clear wood is often regarded as a variable product. The influences acting on the tree include the amount of sunlight, type of soil, temperature, rainfall, heredity, and the like. Fortunately, the variations in the properties of wood usually bear a relation to the specific gravity or density, and

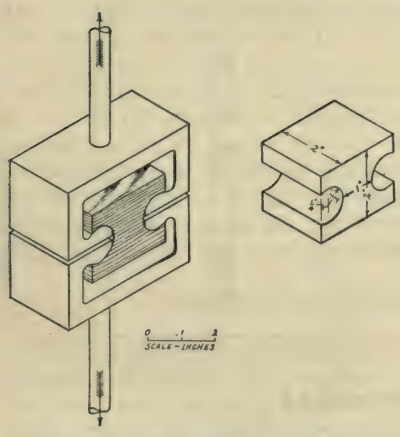


FIGURE 6.—Diagrammatic sketch of method of conducting tension-perpendicular-to-grain test, with details of test specimen

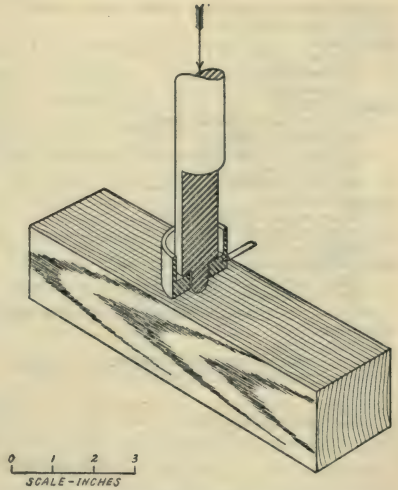


FIGURE 7.—Diagrammatic sketch of method of conducting hardness test

in some cases to physical characteristics, such as proportion of summer wood or rate of growth, so that in cases of importance, selection methods can be used to secure wood of desired properties to meet any given requirements. Accordingly, the variability which is usually thought of as a liability may actually become an asset, particularly inasmuch as a range in properties permits adaptation to a range of uses.

In studying the mechanical properties of wood, tests are made on many specimens of a species. The most useful and convenient method of presenting these test results is in the form of average figures, as is done in Tables 2, 3, and 4. At times, however, it is necessary to know something of the range in properties or of the variability of the results. Table 5 affords a basis for estimating variability of any species with respect to its different properties.

TABLE 5.—*Approximate figures for variation of properties with specific gravity; reliability of averages, and probable deviations of individual specimens from averages*

[For use with Tables 2, 3, and 4]

Property	Approximate power of specific gravity according to which property varies	Probable variation of present average (when from 5 trees) from true species average	Estimated probable variation of an individual piece from average for species
1	2	3	4
		Per cent	*Per cent*
Specific gravity based on volume when green		2.1	8
Weight per cubic foot [1]			
Shrinkage: [1]			
Radial			11
Tangential			10
Volumetric	1		12
Static bending:			
Fiber stress at elastic limit	1¼	5	16
Modulus of rupture	1¼	4	12
Modulus of elasticity	1	5	16
Work to elastic limit	1½	7	
Work to maximum load	1¾	6	23
Impact bending:			
Fiber stress at elastic limit	1¼	4	13
Work to elastic limit	1½	5	
Height of drop	1¾	7	18
Compression parallel to grain:			
Fiber stress at elastic limit	1	5	18
Maximum crushing strength	1	4	13
Compression perpendicular to grain—fiber stress at elastic limit	2¼	6	21
Hardness, end	2¼	4	13
Hardness, side	2¼	5	15
Shearing strength parallel to grain	1¼	3	
Tension perpendicular to grain	2	5	

[1] See explanation, p. 35.

EXPLANATION OF TABLE 5

The figures in Table 5 are presented as an aid and safeguard to the use of data given in Tables 2, 3, and 4 and are explained as follows:

COLUMN 1

The explanation of the properties given in column 1 of Table 5 is the same as that given for Tables 2, 3, and 4.

COLUMN 2

Study of data has shown that each of the shrinkage and strength properties of a given species can be estimated with fair accuracy from the average specific gravity, since each varies approximately according to some power of the specific gravity. This power is given in column 2. However, the specific-gravity relationship to properties should be regarded as a general trend, rather than a perfectly uniform law, as most species usually depart from it in one or more properties. A departure from the general relation that applies to most species usually indicates some exceptional characteristic of a species, which may make it particularly desirable for certain use requirements.

Column 3

The figures in column 3 are derived from the original data on which the averages given in Tables 2, 3, and 4 are based, as well as on additional data, by the use of the processes usually employed to determine the accuracy of experimental data. They are not to be taken as too rigidly applicable to these averages (Tables 2, 3, and 4), but are a convenient approximate measure of the reliability of the averages.

The probable variation of the species average as given in column 3 is a measure of the reliability of the present averages and of the probable change in these averages by additional tests.

Column 4

Column 4 presents an estimate of the probable variation of an individual piece from the average for a species. Conversely, it may be used to estimate the proportion of material falling within any percentage of the average. To illustrate, consider the figure for modulus of rupture, 12 per cent. This means that there is 1 chance in 4 that the modulus of rupture of an individual specimen taken at random will be below 88 per cent of the species average, 1 chance in 4 that it will be above 112 per cent, and 2 chances in 4 that it will be between 88 and 112 per cent of this average. Or, it would be expected that about 50 per cent of the material would fall within ±12 per cent of the average in modulus of rupture.

GENERAL DISCUSSION AND DEDUCTIONS

The sampling and testing of Alaska woods has not been extensive enough to afford as complete an appraisal of the properties and range of properties as might be desired, for it is known that appreciable differences in properties may occur even in adjacent localities. In planning the study, however, it was necessary to keep the work within certain definite limitations, similar to those used in the general study of the properties of woods grown in the United States. It is felt that properly interpreted, the results are a valuable means of appraising the properties and establishing design values.

Tables 2 and 3 show a fairly close agreement in strength values obtained for certain species in Alaska with those for lots of the same species from other regions. Considering the aggregate of six of the most important strength properties, this similarity is evident in the western hemlock from Cordova, Alaska, compared with that from Washington and that from Oregon; in balsam poplar from Girdwood, Alaska, compared with the shipment from Bennington County, Vt.; and in Sitka spruce from Girdwood and Ketchikan, Alaska, compared with the two shipments from Oregon.

Of the various species tested, only western red cedar shows a difference as great as 10 per cent in average properties in favor of any shipment from other parts of the United States. In this case the material from Snohomish County, Wash., was about 10 per cent higher in the average of several properties than that from Ketchikan, Alaska. At the same time the Alaska western red cedar aver-

aged higher by about 7 per cent than did that from Missoula County, Mont. These differences may be due to chance in sampling, or at most, can be regarded as applicable to the particular and immediate sites from which the samples were taken. They should not necessarily be interpreted, however, as representing the relative strengths of this species in these respective general geographical regions.

On the other hand, it may be noted that in six cases the averages of the Alaska material, by localities, are 10 per cent or more higher in the principal strength properties than certain individual shipments from other regions of the United States. These cases are found in Alaska cedar, mountain hemlock, western hemlock, and Sitka spruce.

In considering the causes of variations in properties of wood, it may first be observed that there are many factors affecting tree growth. Immediate site factors, such as soil, soil moisture, and competition for light and food, are subject to large variations within small areas, and are further subject to large variations within the life of the tree. Their effect, within the normal range of a species, is seemingly of greater importance than geographical location, as is shown by significant differences in strength properties of samples of a species from adjacent areas and from the inner and outer portions of the same tree and similarity in strength of samples from widely separated regions.

A specific example is noted in Sitka spruce. Tests show differences between averages of samples from two localities in Oregon of 12 per cent in specific gravity and 20 per cent or more in modulus of rupture, which is several times the probable difference that would be expected considering all Sitka spruce as belonging to the same population. In contrast, the average for samples of Sitka spruce from near Ketchikan, Alaska, tested in a green condition, was identical in specific gravity with that of one of these groups of samples from near Portland, Oreg., and was within a few per cent in modulus of rupture. These and similar observations lead to the general conclusion that, in the absence of specific data concerning any given lot of material, the general average of all material for the species is a more reliable estimate of the strength properties than data on samples from adjacent localities or from sites that appear to be the same. This does not mean, however, that there may not be differences apparent in the grade and quality of wood from different stands, such as prevalence of defects, seasoning characteristics, and the like, sufficient in importance to justify marketing preferences.

The whole problem of the effect of region, site, and conditions of stand on wood properties is an exceedingly complicated one, and sufficient data are not available nor has sufficient study been made to attempt a final appraisal. The data show quite conclusively that the mechanical properties of woods from the coastal forests of Alaska are fully the equal of those of the same species grown elsewhere. Moreover, the growth conditions appear to be favorable to the production of timber of good strength properties.

The average strength values for the species given in Table 4, which are based on all comparable tests made at the Forest Products

Laboratory, are accordingly recommended as a basis for species comparison. They may likewise be used in wood design where the properties of clear material are required or as a basis for arriving at safe working stresses for structural timbers. Comparisons with other species not listed in Table 4 may be made by means of Department Bulletin 556 (*17*); or if a less technical discussion of simplified strength properties is desired the data on Alaska woods combined with that of the same species from other regions will be found in Technical Bulletin 158 (*13*).

Taken as a whole, the information presented in Tables 2, 3, and 4 shows that the different Alaska species have a large range in properties and are available to fill many diverse demands in addition to the pulp and paper possibilities, which offer the most significant outlet for Alaska woods.

TESTS OF FULL-SIZED SAWED STRUCTURAL TIMBERS OF SITKA SPRUCE AND WESTERN HEMLOCK[6]

SELECTION OF MATERIAL

Sitka Spruce

The Sitka spruce logs from which the structural timber test material was taken were cut in the Tongass National Forest, near Ketchikan, and were from 300 to 400 years old. The logs were sawed at Ketchikan. Twenty 8 by 16 inch by 32-foot timbers, which were selected by representatives of the Forest Service, arrived at the former Seattle laboratory of the Forest Service shortly after manufacture. Although some of the pieces showed surface checking when received, the material was still in an essentially unseasoned condition. On arrival at Seattle, Wash., the timbers were numbered and cut into 16-foot lengths, after which they were graded in accordance with the export rules of the Pacific Lumber Inspection Bureau by one of their representatives.

In selecting the 32-foot stringers an effort was made to obtain pieces that could each be cut into two 16-foot lengths of the same grade, the object being to alternate the butt and top 16-foot pieces for tests of green and air-seasoned material, the green portion to consist in equal parts of high and low density pieces of the same grades and the air-seasoned portion to be made up in the same way, thus obtaining as nearly perfect matching of the two portions as possible. However, it was impracticable to obtain the 32-foot stringers in exactly the way desired, but after they were cut into 16-foot lengths and regraded, the green and seasoned pieces, alternating butt and top, matched well for both grade and density. Immediately after the material was regraded tests were started on the stringers to be tested in the green condition. The other half was stored under cover for air seasoning and were tested after drying.

Western Hemlock

The western hemlock logs from which the test material was taken were cut in the Tongass National Forest, near Ketchikan. The test

[6] The tests were made by C. W. Zimmerman and H. Curtis Stinson, of the former Seattle laboratory of the Forest Service.

material, as in the case of the Sitka spruce, comprised timbers 8 by 16 inches by 32 feet, but consisted of two independent shipments.

The first shipment comprised 20 green stringers, which were received in Seattle in July, 1922. They were promptly taken to the laboratory, and there cut into 16-foot lengths, marked, graded, and divided into two matched groups for tests of green and of seasoned material.

The pieces to be tested green were kept from seasoning by storing in a bin and covering with wet sawdust, a treatment being applied to retard molding. The pieces intended for air seasoning were open piled under an open shed. They were weighed monthly until time of test to determine the rate of seasoning, and were allowed to air dry two years before testing.

The second shipment of western hemlock comprised nine green stringers, which were received in Seattle, November, 1922. The subsequent procedure was similar to that just described for the first shipment.

CHARACTER OF TESTS

The tests on both Sitka spruce and western hemlock were of two kinds; (1) on full-sized structural members, and (2) on small, clear specimens cut from them. The study of small, clear specimens was made to determine the strength of the wood free from defects as compared with the structural sizes containing defects. The procedure used corresponded to that of the American Society for Testing Materials (*4*), except that on the small, clear specimens no hardness tests were made, 6 rather than 12 shear-parallel-to-grain specimens were tested, and the compression-perpendicular-to-grain specimens were 2 by 2 by 8 inches rather than 2 by 2 by 6 inches.

The tests on large pieces consisted of bending, compression parallel to grain, and compression perpendicular to grain; the minor tests on small, clear pieces consisted of static bending, compression parallel to grain, compression perpendicular to grain, and shear parallel to grain.

Tests on Large Pieces

BENDING

The static bending tests were made on 8 by 16 inch by 16 foot beams, using a 15-foot span and "third-point" loading, which consists of two symmetrical loads spaced one-third of the span. (Pl. 9.) Six beams were tested with spans slightly less than 15 feet.

COMPRESSION PARALLEL TO GRAIN

Two compression-parallel-to-grain specimens (5½ by 5½ by 24 inches) were taken from the uninjured portion of each beam after the bending test.

COMPRESSION PERPENDICULAR TO GRAIN

One compression-perpendicular-to-grain specimen (8 by 16 by 30 inches) was obtained from each timber after the bending test.

Tests on Small, Clear Specimens

Tests on small, clear specimens cut from the uninjured portion of the large beams, consisted for each beam of 6 static bending specimens (2 by 2 by 30 inches), 6 compression-parallel-to-grain specimens (2 by 2 by 8 inches), 3 compression-perpendicular-to-grain specimens (2 by 2 by 8 inches), and 6 shear-parallel-to-grain specimens (2 by 2 by 2½ inches). The testing procedure conformed in most details to that of the American Society for Testing Materials (*2*).

TEST RESULTS

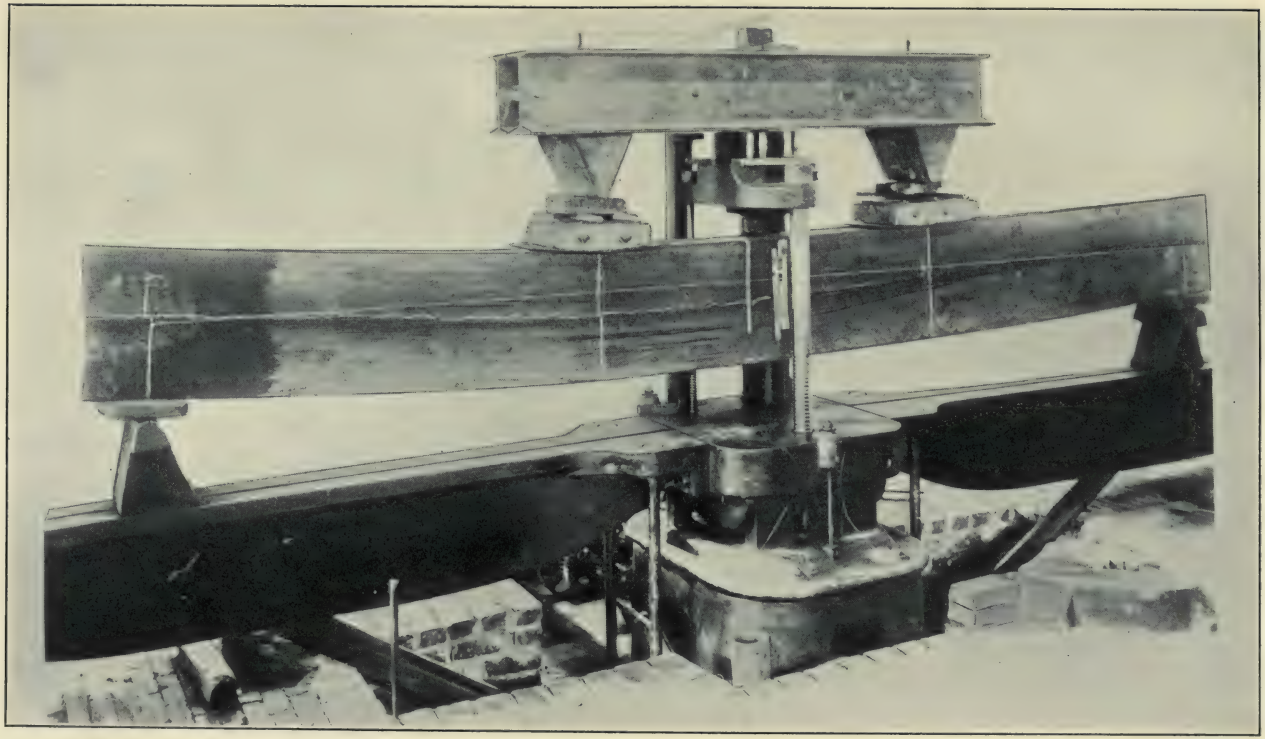
A summary of the results of tests on the western hemlock and Sitka spruce structural timbers is presented in Table 6. The results for individual timbers will be found in the appendix.

These data are in general conformity with deductions which have been previously published (*6*, *14*, *15*, *16*). The results show that the strength of structural timbers is dependent on the size and location of defects; that defects develop in large timbers with seasoning and thus tend to offset the gain in strength with loss of moisture; that knots seriously affect the bending strength (modulus of rupture), and have little effect on stiffness (modulus of elasticity); that individual timbers vary in strength because of differences in density or dry weight of the wood; and that the test values are related to safe working stresses, the engineer's guide in all timber design work.

TABLE 6.—*Average results of tests on structural timbers from Alaska and of small, clear specimens cut from them*

Species	Condition when tested	Type of specimen	Static bending											
			Tests	Cross section	Span	Loading	Moisture content	Specific gravity	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Horizontal shear stress at maximum load
			No.	*Inches*	*Inches*		*Per cent*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Pounds*
Western hemlock	Green	Structural	29	8 by 16	180	Third point	41.6	0.43	3,150	4,880	1,350	0.69	3.5	330
Do	do	Small, clear	174	2 by 2	28	Center	43.3	.43	3,860	7,030	1,340	.64	8.5	250
Sitka spruce	do	Structural	20	8 by 16	180	Third point	34.2	.36	2,290	4,160	1,250	.38	3.3	280
Do	do	Small, clear	119	2 by 2	28	Center	37.2	.35	2,440	5,360	1,290	.28	5.6	190
Western hemlock	Air seasoned	Structural	29	8 by 16	180	Third point	17.5	.44	3,940	5,750	1,520	.95	2.9	390
Do	do	Small, clear	174	2 by 2	28	Center	8.5	.46	8,440	13,460	1,780	2.25	10.4	470
Sitka spruce	do	Structural	20	8 by 16	180	Third point	17.3	.37	3,800	5,310	1,400	.96	2.9	350
Do	do	Small, clear	120	2 by 2	28	Center	14.6	.37	5,120	8,470	1,410	1.05	9.2	300

Species	Condition when tested	Type of specimen	Compression parallel to grain				Compression perpendicular to grain				Shearing strength parallel to grain		
			Tests	Moisture content	Specific gravity	Maximum crushing strength	Tests	Moisture content	Specific gravity	Fiber stress at elastic limit	Tests	Moisture content	Average of radial and tangential shear
			No.	*Per cent*		*Lbs. per sq. in.*	*No.*	*Per cent*		*Lbs. per sq. in.*	*No.*	*Per cent*	*Lbs. per sq. in.*
Western hemlock	Green	Structural	50	41.0	0.42	3,140	29	42.3	0.42	360			
Do	do	Small, clear	174	42.8	.42	3,200	87	48.2	.45	400	163	79.7	710
Sitka spruce	do	Structural	37	35.0	.36	2,510	20	35.7	.36	180			
Do	do	Small, clear	119	35.8	.35	2,530	60	36.6	.35	260	120	35.7	650
Western hemlock	Air seasoned	Structural	58	9.7	.45	6,840	29	17.7	.44	580			
Do	do	Small, clear	174	8.2	.46	8,590	87	8.5	.46	740	142	9.3	1,130
Sitka spruce	do	Structural	33	14.9	.37	4,560	18	15.1	.38	440			
Do	do	Small, clear	118	13.4	.37	4,860	54	13.8	.38	470	107	12.8	850



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FOREST SERVICE METHOD OF TESTING TIMBERS OF STRUCTURAL SIZE. THE BEAM IS 8 BY 16 INCHES IN CROSS SECTION AND IS BEING TESTED UNDER THIRD-POINT LOADING OVER A SPAN OF 15 FEET

The Sitka spruce timbers, which were cut from relatively large trees, were uniformly of high grade and in many cases of entirely clear wood on the exposed faces. It is obviously possible to secure much high-grade structural timber from Alaska-grown Sitka spruce, and this species should be very useful, particularly for local requirements. Considering the many desirable properties and characteristics of the species, however, which make it so satisfactory for higher-class uses, such as airplane wing beams and musical-instrument sounding boards, it is hardly to be expected that Sitka spruce need enter competition with other species in the structural-timber field. Its lack of natural decay resistance, furthermore, precludes its use for timbers to be used under conditions favorable to decay, except when treated with creosote or other wood preservatives.

With western hemlock, the situation is quite the reverse. Only the largest western hemlock trees are big enough to furnish long timbers of the 8x16-inch bridge-stringer size tested, and these are most naturally obtained from the butt cuts. The western hemlock timbers as a whole were of much lower grade than the Sitka spruce, because of the prevalent heart rot in the large overmature trees, the many shakes and inclosed bark pockets in the butt timbers, and the numerous rotten knots. It appears, therefore, that while western hemlock has excellent strength properties, and timbers of high grade can be secured by proper selection at the mill, the possibility of producing large-sized timbers of this species for export is not encouraging. On the other hand, there are many local uses where western hemlock timbers may be admirably adapted, perhaps to replace imported woods, and these data should furnish a sound basis and encouragement for such utilization. This is, of course, aside from the use of western hemlock for dimension, for lumber purposes, for material in the form of small, clear stock, and for pulpwood requirements.

Safe working stresses recommended by the Forest Products Laboratory for Alaska-grown woods and other common woods for the American lumber standards grades of select and common are given in the appendix.

Structural grading rules conforming to American lumber standards and specifications for timbers for different uses requiring both treated and untreated material have been adopted and published by the American Society for Testing Materials (*3*) and the American Railway Engineering Association (*1*). These specifications are excellent from both the technical and practical engineering standpoint, and are recommended for use with structural timbers of Alaska species.

TESTS OF FULL-SIZED ROUND MINE TIMBERS OF ALASKA BIRCH, WESTERN HEMLOCK, SITKA SPRUCE, AND WHITE SPRUCE[7]

SELECTION OF MATERIAL

The material for test consisted of 15 round props and 15 caps each of white spruce, Alaska birch, Sitka spruce, and western hemlock.

[7] The tests were made by C. W. Zimmerman, of the former Seattle laboratory of the Forest Service.

The material was grown on the Chugach National Forest and was representative of the market run of timber. The timbers were nominally 5 to 6 inches in top diameter, the props were 6 feet in length, and the caps 8 feet. They were received and tested in a green condition at the former Seattle laboratory of the Forest Service.

CHARACTER OF TESTS

The method of testing was identical to the procedure described and illustrated in Department Bulletin 77 (*5*).

The 6-foot props were tested in compression parallel to the grain, the descent of the movable head of the testing machine being 0.12 inch per minute. The compression of the prop was measured between the movable testing machine head and the weighing platform.

The 8-foot caps were tested in bending on a 7-foot span with third-point loading. The rate of descent of the movable head of the testing machine was 0.23 inch per minute. Deflections were taken at the center of the specimen.

TEST RESULTS

Table 7 presents a summary of the results of compression tests of mine props of four Alaska woods, together with similar data on a number of species from Colorado. Table 9 presents like information with respect to the bending tests of mine caps. The test values for individual timbers from Alaska are given in the appendix. The data on woods from Colorado are taken from Department Bulletin 77 (*5*).

TABLE 7.—*Average results of crushing tests of green round mine props from Alaska compared with those from other regions*

(Nominal size, 5-inch top diameter by 6 feet long)

Species	Place of growth of material tested	Trees tested	Moisture content	Approximate dry weight (volume as tested)	Rings per inch	Summer wood	Sapwood
		Number	*Per cent*	*Lbs. per cu. ft.*	*Number*	*Per cent*	*Per cent*
Alaska birch	Chugach National Forest, Alaska.	15	68.4	32.7			
Western hemlock	do	15	68.1	31.9	46		
Sitka spruce	do	15	50.6	29.9	46		
White spruce	do	15	83.7	25.3	33		
Alpine fir	Colorado	9	91.0	21.4	26	15	
Douglas fir (mountain type)	do	10	50.5	27.5	39	23	37
Bristlecone pine	do	10	85.9	27.7	35	20	46
Lodgepole pine	do	10	75.7	23.8	40	18	54
Do	Boulder County, Colo	10	70.8	22.9	43	16	48
Western yellow pine	Pike National Forest, Colo	10	96.1	23.2	14	15	
Do	Gunnison National Forest, Colo	10	82.0	24.8	18	16	
Engelmann spruce	Pike National Forest, Colo	11	62.3	24.1	32	16	

TABLE 7.—*Average results of crushing tests of green round mine props from Alaska compared with those from other regions*—Continued

Species	Place of growth of material tested	Trees tested	Diameter		Crushing strength at maximum load	Crushing strength at elastic limit	Modulus of elasticity
			Top	Butt			
		Number	*Ins.*	*Ins.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq.in.*
Alaska birch	Chugach National Forest, Alaska.	15	5.76	6.15	2,870	2,250	1,352
Western hemlock	do	15	5.86	6.36	3,060	2,230	1,224
Sitka spruce	do	15	4.84	5.81	2,460	1,681	1,040
White spruce	do	15	5.64	6.16	2,620	2,230	1,229
Alpine fir	Colorado	9	4.90	5.65	1,920	1,490	541
Douglas fir (mountain type)	do	10	5.48	6.05	2,580	2,130	758
Bristlecone pine	do	10	4.58	5.38	1,660	1,310	508
Lodgepole pine	do	10	5.73	6.18	1,860	1,490	599
Do	Boulder County, Colo.	10	5.90	6.58	1,600	1,240	496
Western yellow pine	Pike National Forest, Colo.	10	4.44	5.20	1,470	1,200	443
Do	Gunnison National Forest, Colo.	10	5.35	6.00	1,940	1,450	561
Engelmann spruce	Pike National Forest, Colo.	11	4.95	5.80	1,750	1,350	529

MINE PROPS

It may be seen from Table 7 that Douglas fir[8] averaged the strongest of the six species from Colorado. With the exception of Sitka spruce, however, each of the Alaska species tested averaged higher than Douglas fir (Rocky Mountain type) in crushing strength. The Sitka spruce, although a little below the Douglas fir. withstood greater average unit crushing stress than any of the other Rocky Mountain species in this series of tests. Western larch, which is higher in strength than Douglas fir (Rocky Mountain type) and is used as a mine timber in the Rocky Mountain region, was not included in these tests of mine props or mine caps.

Table 8, in which the maximum crushing strength of the green mine props is given as a percentage of Douglas fir from the Rocky Mountains, may better serve to bring out these comparisons. Values based on standard tests of small, clear specimens are also given for the same species in a green condition.

TABLE 8.—*Maximum crushing strength of green mine props and small, clear specimens of Alaska and Rocky Mountain species*

[Douglas fir considered as 100 per cent]

Source and species	Maximum crushing strength	
	Mine props	Small, clear specimens
	Per cent	*Per cent*
Alaska:		
Alaska white birch	111	101
Western hemlock	119	101
Sitka spruce	95	92
White spruce	102	91
Rocky Mountains:		
Douglas fir	100	100
Alpine fir	74	69
Bristlecone pine	64	
Lodgepole pine	67	87
Western yellow pine	66	79
Engelmann spruce	68	66

[8] Douglas fir from Colorado is classed as belonging to the Rocky Mountain type, which averages lower in strength than that from the Pacific Northwest. Comparison of Alaska species is made with species from Colorado because no data on mine timbers are available for material from the Pacific Northwest.

Table 8 shows that the Alaska white birch, western hemlock, Sitka spruce, and white spruce from Alaska compared favorably with some of the species commonly used for mine props in the Rocky Mountain region.

MINE CAPS

From Table 9 it may be observed that Douglas fir leads the other Rocky Mountain species in bending strength tests of mine caps. Each of the Alaska species tested with the exception of white spruce averaged higher than the Douglas fir (Rocky Mountain type) in modulus of rupture, and the white spruce averaged higher than the other Rocky Mountain woods.

TABLE 9.—*Average results of bending tests of green round mine caps from Alaska compared with those from other regions*

(Nominal size, 5-inch top diameter by 8 feet long; span 7 feet; third-point loading)

Species	Place of growth of material tested	Trees tested	Moisture content	Approximate dry weight (volume as tested)	Rings per inch	Summer wood	Sapwood
		Number	*Per cent*	*Lbs. per cu. ft.*	*Number*	*Per cent*	*Per cent*
Alaska birch	Chugach National Forest, Alaska.	15	77.7	31.3			
Western hemlock	do	15	58.6	33.4	54		
Sitka spruce	do	15	45.4	29.8	46		
White spruce	do	15	81.4	25.2	38		
Alpine fir	Colorado	9	99.5	19.6	21	16	
Douglas fir (mountain type)	do	10	69.4	26.5	27	22	50
Bristlecone pine	do	10	74.3	27.5	37	14	53
Lodgepole pine	do	10	89.3	23.9	43	19	54
Do	Boulder County, Colo	10	60.6	23.8	43	15	40
Western yellow pine	Pike National Forest, Colo	10	88.5	20.9	13	14	
Do	Gunnison National Forest, Colo.	10	147.1	22.2	26	17	
Engelmann spruce	Pike National Forest, Colo	11	54.3	24.0	30	20	

Species	Place of growth of material tested	Trees tested	Diameter		Modulus of rupture	Fiber stress at elastic limit	Stiffness [1] factor $\frac{P}{Id}$
			Top	Butt			
		Number	*Inches*	*Inches*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
Alaska birch	Chugach National Forest, Alaska.	15	5.70	6.22	8,640	4,130	171.1
Western hemlock	do	15	5.88	6.47	8,500	4,010	137.1
Sitka spruce	do	15	5.76	6.74	7,080	3,270	119.0
White spruce	do	15	6.18	6.97	6,340	3,550	132.9
Alpine fir	Colorado	9	4.65	5.72	4,140	2,450	79.3
Douglas fir (mountain type)	do	10	4.78	5.66	6,570	3,460	85.2
Bristlecone pine	do	10	4.63	5.62	4,580	2,460	66.6
Lodgepole pine	do	10	5.59	6.20	5,170	3,100	108.9
Do	Boulder County, Colo	10	5.78	6.45	4,770	2,760	86.0
Western yellow pine	Pike National Forest, Colo.	10	4.39	5.60	4,330	2,170	74.5
Do	Gunnison National Forest, Colo.	10	4.42	5.45	4,900	2,890	72.6
Engelmann spruce	Pike National Forest, Colo.	11	5.16	6.40	5,310	2,710	95.0

[1] Owing to the taper of round mine caps, a stiffness factor has been used instead of modulus of elasticity. In this factor P equals the total load in pounds, I equals the moment of inertia, and d equals the deflection in inches at the center of the span.

A comparison of the modulus of rupture of the green mine caps and of small clear specimens in a green condition is presented in Table 10 for the Alaska and Rocky Mountain species.

TABLE 10.—*Modulus of rupture of green mine caps and of small clear specimens in a green condition, Alaska and Rocky Mountain species*

Source and species	Modulus of rupture	
	Mine caps	Small, clear specimens
	Per cent	*Per cent*
Alaska:		
Alaska white birch	132	111
Western hemlock	129	95
Sitka spruce	108	91
White spruce	97	89
Rocky Mountains:		
Douglas fir	100	100
Alpine fir	63	69
Bristlecone pine	70	----
Lodgepole pine	76	86
Western yellow pine	70	78
Engelmann spruce	81	66

The Alaska woods did not show so high ratios on the basis of the small, clear specimens as when compared by means of the results of tests on mine caps. However, even on the basis of the small, clear specimens, the Alaska white birch averaged higher in bending strength than the Rocky Mountain Douglas fir, and the other Alaska species listed exceeded the Rocky Mountain alpine fir, lodgepole pine, western yellow pine, and Engelmann spruce in modulus of rupture.

CONCLUSIONS

The conclusions from the study of mine props and caps are that the four Alaska woods tested are on the whole about as high as or higher in strength than Douglas fir from the Rocky Mountains, and are superior in strength to the other common Rocky Mountain species used for mine timbers on which data are presented.

The data given for mine timbers are for material free from decay. It is, of course, recognized that decay is one of the principal factors to be considered in the use of timbers in mines. The heartwood of the more decay-resistant species, or preservative treatment, may be resorted to when longer life than that ordinarily to be expected is desired (*11*).

The mine timbers tested, of course, contained some defects, but it was not feasible in testing to obtain a record in such a way as to attempt to take defects into account in comparing the species. For this reason, and the fact that there is a considerable range in the density of the clear wood of any species, it is not to be expected that the exact percentages shown would be duplicated in additional tests. The figures from the mine-timber tests, therefore, should not be taken too literally in considering the relative strength of the species. In fact, the data from the tests of small, clear specimens will afford a somewhat closer appraisal of the relative species values for mine purposes than the results of the mine-timber tests themselves, although the mine-timber tests are essential for arriving at

design stresses. It is evident from these data that Alaska woods can be used to advantage for mine purposes.

SUMMARY

The Alaska forests are of two distinct kinds. The forests of the interior, covering approximately 50,000,000 acres, are of the woodland type, very slow in growth and light in stand. It is unlikely that much of the interior timber will ever reach the general market, but it has a high potential value for local use in the development of the mining and agricultural resources of the vast region over which it grows. On the other hand, the coastal forests covering 21,347,000 acres of southern and southeastern Alaska, comprised principally in the Chugach and Tongass National Forests, are of great importance commercially. They are of luxuriant growth and may be regarded as an extension of the coastal forests of Oregon, Washington, and British Columbia. These national forests are under the administration of the Forest Service, and are estimated to contain 84,760,000,000 feet, board measure, of saw timber.

The annual cut of the two coastal forests, which amounted to 47,462,000 board feet in 1929, represents but a small fraction of the estimated annual sustained yield for pulpwood purposes. The sale of timber by the Forest Service on a sustained-yield basis offers the assurance of a continuous supply and permanent local industries.

The data presented from tests of small, clear specimens permit comparison of the mechanical properties of Alaska species with a large number of other woods. The results show that Alaska woods are fully equal in strength to the same species grown elsewhere in the United States.

The tests on large sawn timbers containing defects show that western hemlock, Sitka spruce, and other Alaska species may be used satisfactorily as structural timbers when properly graded. Likewise, the tests of round mine timbers show that Alaska white birch, western hemlock, white spruce, and Sitka spruce compare very favorably in strength with the best of the Rocky Mountain softwoods, and exceed in strength most of the species locally available in the Rocky Mountain region for mine timbers.

Large areas suitable mainly for timber production, a present forest utilization of but a fraction of the actual and potential annual growth, a variety of species with a large range in properties, an abundance of water power and timber resources which are favorable to pulpwood development—these considerations presage for Alaska an increasing economic forest development.

APPENDIX

DETAILED RESULTS OF STRUCTURAL TIMBER TESTS

Tables 11 to 14 present the results of tests for each of the individual western hemlock and Sitka spruce structural timbers studied.

The modulus of rupture of the poorest structural timbers meeting the requirement of any structural grade should be about three times the allowable fiber stress in bending. This requirement is based on a factor of nine-sixteenths to keep the stress within the elastic limit for long-continued loading, and a factor of three-fifths, so that three times the allowable fiber stress in bending represents an actual factor of safety of one and two-thirds for a timber on the border line of the grade. Tables 13 and 17 show that the Sitka spruce timber (No. 20) with the lowest modulus of rupture (2,700 pounds per square inch) should be a cull because of severe cross grain. The poorest acceptable piece (No. 19), under the requirements of the American lumber standards grade of Select, which permits defects that reduce the strength by one-fourth, has a modulus of rupture of 3,330 pounds per square inch. The safe working stresses, as given in the appendix, present an allowable fiber stress in bending for the select grade of Sitka spruce when used under continuously dry conditions of 1,100 pounds per square inch, which brings the poorest acceptable timber (No. 19) just within the three-to-one limit relationship acceptable between test values and working stress.

TABLE 11.—*Detailed data on the individual structural timbers of green western hemlock from Alaska and of small, clear specimens cut from them*

Specimen No.	Type of specimen	Actual cross-section		Span	Static bending								Compression parallel to grain			Compression perpendicular to grain			Shearing strength parallel to grain	
					Moisture content	Specific gravity	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Horizontal shear stress at maximum load	Moisture content	Specific gravity	Maximum crushing strength	Moisture content	Specific gravity	Fiber stress at elastic limit	Moisture content	Average of radial and tangential
		Inches	*Inches*	*Inches*	*Per cent*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
1	Structural	8.13	16.44	180	34.4	0.396	3,300	5,340	1,308	0.76	5.23	365	33.8	0.385	2,400	33.7	0.401	328		
	Small, clear	2.00	2.00		45.3	.462	3,425	5,955	1,223	.54	4.51	215			2,828	62.0	.426	483	101.6	674
12	Structural	7.98	16.34	180	47.0	.400	3,240	5,160	1,315	.73	6.55	349	42.8	.381	3,160	51.2	.392	292		
	Small, clear	2.60	2.00		47.0	.386	3,665	6,677	1,360	.53	5.80	215	46.8	.380	2,873	40.5	.404	244	68.1	563
13	Structural	8.16	16.36	180	42.5	.428	4,200		1,077	1.49	3.47		54.5	.449	2,615	43.8	.413	360		
	Small, clear	2.00	2.00		37.2	.431	3,995	6,982	1,478	.61	7.74	245	40.5	.411	3,342	38.6	.438	372	55.4	770
14	Structural	7.82	16.10	180	37.6	.433	3,580	5,560	1,552	.75	3.40	371	38.1	.422	3,510	39.6	.417	275		
	Small, clear	2.00	2.00		43.5	.376	3,607	6,868	1,420	.51	10.22	245	38.7	.381	3,057	41.2	.398	272	52.1	611
15	Structural	8.03	16.17	180	46.3	.486	3,980	6,640	1,632	.88	9.57	445	40.2	.447	3,730	52.5	.446	283		
	Small, clear	2.00	2.00		51.3	.469	4,290	8,323	1,280	.80	14.09	301	51.6	.464	3,698	52.9	.461	477	96.8	811
16	Structural	8.38	16.33	180	43.9	.381	2,930	4,230	1,166	.67	2.08	286	41.6	.398	2,895	41.5	.403	417		
	Small, clear	2.00	2.00		35.7	.368	3,040	5,395	1,121	.46	4.97	194	44.9	.351	2,600	39.1	.360	255	54.1	600
7	Structural	8.34	16.16	180	39.7	.415	3,590	5,640	1,486	.79	7.06	378	40.2	.397	3,315	42.0	.408	319		
	Small, clear	2.00	2.00		37.6	.419	3,833	7,177	1,520	.54	10.92	259	37.9	.405	3,200	34.8	.389	251	69.0	716
18	Structural	8.08	16.23	180	47.2	.444	3,420	5,860	1,513	.70	5.86	394	43.5	.433	3,400	52.3	.448	288		
	Small, clear	2.00	2.00		47.8	.403	4,400	7,495	1,598	.68	7.79	268	43.3	.420	3,685	44.7	.436	280	62.5	708
19	Structural	7.89	16.34	180	30.7	.376	3,360	4,690	1,338	.77	3.15	318	31.7	.367	2,620	31.2	.368	213		
	Small, clear	2.00	2.00		39.9	.372	3,232	6,060	1,307	.45	5.53	218			2,742	52.0	.417	351	103.0	532
10	Structural	8.14	16.36	180	36.6	.467	2,930	4,830	1,311	.59	2.69	327	42.0	.451	2,885	41.3	.451	451		
	Small, clear	2.00	2.00		40.4	.450	3,565	6,257	935	.84	9.35	226			2,797	57.5	.480	476	86.8	813
11	Structural	8.39	16.80	180	43.0	.399	3,040	4,640	1,296	.64	2.26	322	39.2	.393	2,655	46.5	.396	268		
	Small, clear	2.00	2.00		50.6	.402	3,408	6,015	1,338	.48	5.34	216			2,812	61.3	.431	387	97.0	581
12	Structural	7.89	16.08	180	37.3	.445	3,570	5,420	1,442	.80	3.81	361	44.4	.409	3,150	34.7	.442	435		
	Small, clear	2.00	2.00		47.5	.454	4,010	7,192	1,281	.70	7.82	260			3,178	57.9	.482	775	88.1	802
13	Structural	8.23	16.49	180	43.6	.433	2,570	4,460	1,092	.54	3.28	304	40.6	.411	2,590	39.6	.411	342		
	Small, clear	2.00	2.00		41.0	.425	3,312	5,983	1,236	.50	5.98	217			2,542	61.0	.433	397	109.5	652
14	Structural	7.99	16.34	180	40.0	.449	3,450	5,670	1,533	.70	3.46	384	51.8	.476	4,125	42.2	.456	317		
	Small, clear	2.00	2.00		38.1	.450	4,213	7,650	1,572	.64	7.65	275	37.3	.450	3,587	34.4	.468	309	60.4	756
15	Structural	7.65	16.35	172	35.7	.493	5,250	5,620	1,498	1.68	2.18	399	34.0	.495	3,985	36.1	.460	457		
	Small, clear	2.00	2.00		48.1	.488	4,268	7,953	1,388	.75	12.50	286			3,862	52.2	.520	520	89.8	698

[1] 16	Structural	7.87	16.17	180	37.9	.438	3,230	5,450	1,641	.58	3.89	365	39.5	.428	3,405	38.1	.439	265		
	Small, clear	2.00	2.00		35.8	.425	3,927	7,758	1,560	.55	11.45	279	37.7	.419	3,292	35.1	.421	304	62.7	678
17	Structural	8.87	16.37	180	39.1	.430	3,440	5,260	1,248	.86	2.76	356	35.0	.422	3,375	40.2	.417	371		
	Small, clear	2.00	2.00		36.3	.449	3,758	7,505	1,256	.61	12.08	269	36.3	.444	3,583	34.3	.465	321	67.5	730
[1] 18	Structural	7.99	16.28	180	53.1	.450	3,010	5,140	1,354	.60	3.57	346	56.3	.458	3,335	46.4	.468	527		
	Small, clear	2.00	2.00		52.7	.486	3,970	7,492	1,252	.73	7.96	270	54.1	.477	3,612	42.4	.542	556	69.7	910
[1] 19	Structural	7.98	16.49	180	58.7	.422	2,820	4,540	1,262	.57	2.24	309	48.6	.400	2,795	61.2	.407	259		
	Small, clear	2.00	2.00		46.6	.421	3,640	6,658	1,170	.65	7.85	243	52.4	.410	3,152	46.8	.467	472	82.6	732
20	Structural	8.25	16.31	180	40.0	.444	2,950	5,040	1,398	.56	2.39	340	35.2	.430	3,795	45.7	.436	274		
	Small, clear	2.00	2.00		34.1	.448	3,923	7,652	1,280	.70	9.18	275	34.0	.441	3,570	35.7	.458	261	59.5	810
21	Structural	8.07	15.92	180	42.6	.410	2,900	4,340	1,332	.57	1.92	271	41.7	.392	2,850	42.2	.418	364		
	Small, clear	2.00	2.00		43.5	.438	3,925	6,800	1,213	.74	7.32	243			3,245	49.4	.491	639	89.8	764
22	Structural	8.37	16.38	180	52.2	.419	2,480	4,370	1,336	.41	1.98	296	49.7	.410	3,095	55.2	.415	292		
	Small, clear	2.00	2.00		52.7	.402	3,928	6,855	1,506	.58	7.40	246	53.2	.403	2,925	50.4	.400	210	75.2	690
[1] 23	Structural	8.18	16.55	180	40.5	.449	2,090	4,420	981	.40	3.89	302	33.2	.435	3,165	43.2	.420	491		
	Small, clear	2.00	2.00		42.5	.449	3,890	7,020	1,063	.84	10.60	254			2,902	57.8	.469	550	86.0	824
24	Structural	8.08	16.00	172	34.3	.428	3,020	4,720	1,253	.66	2.66	327	32.7	.442	3,140	34.0	.414	398		
	Small, clear	2.00	2.00		43.2	.462	4,170	7,608	1,557	.62	8.47	273			3,343	50.1	.505	420	101.3	728
[1] 25	Structural	8.23	16.42	180	42.8	.435	2,310	3,700	1,193	.40	1.32	250	41.1	.375	2,550	40.8	.420	628		
	Small, clear	2.00	2.00		57.0	.435	3,522	6,460	1,102	.68	7.23	230			2,892	66.5	.436	544	92.0	632
26	Structural	8.27	16.36	180	31.5	.416	2,880	3,950	1,200	.62	1.54	267	31.8	.412	2,870	31.5	.392	486		
	Small, clear	2.00	2.00		42.4	.440	3,732	6,948	1,269	.61	7.35	253			3,060	63.1	.416	275	114.9	601
[1] 27	Structural	8.14	16.34	180	44.4	.470	3,480	4,420	1,494	.73	1.36	298	46.4	.474	3,135	47.5	.449	344		
	Small, clear	2.00	2.00		40.3	.461	4,583	8,230	1,399	.85	12.23	286	43.0	.457	3,820	50.6	.462	361	71.4	790
[1] 28	Structural	8.25	16.39	180	45.2	.398	2,470	3,770	1,366	.40	1.22	255	37.5	.404	3,230	39.3	.403	336		
	Small, clear	2.00	2.00		35.1	.377	4,165	7,708	1,633	.63	7.95	266	32.3	.377	2,873	34.8	.375	252	61.7	706
[1] 29	Structural	8.12	16.12	168	37.9		1,990	3,740	1,484	.25	2.13	269				34.0	.429	315		
	Small, clear	2.00	2.00		41.6	.498	4,563	7,718	1,450	.83	8.14	277			3,818	52.0	.520	497	82.9	743

[1] This timber contained one or more rotten knots which would not be permissible in structural timbers meeting the requirements of American lumber standards. The depth of rot was not recorded, but if the depth does not exceed the diameter of the knot, the timber may be graded as if the knot were sound, according to the principles of grading in U. S. Dept. Agr. Cir. 295. If the depth of rot at a knot exceeds the diameter, the timber would be graded as S4 or a cull by the grading principles of U. S. Dept. Agr. Cir. 295.

TABLE 12.—*Detailed data on the individual structural timbers of air-dry western hemlock from Alaska and of small, clear specimens cut from them*

Specimen No.	Type of specimen	Actual cross-section		Span	Static bending								Compression parallel to grain			Compression perpendicular to grain			Shearing strength parallel to grain	
					Moisture content	Specific gravity	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Horizontal shear stress at maximum load	Moisture content	Specific gravity	Maximum crushing strength	Moisture content	Specific gravity	Fiber stress at elastic limit	Moisture content	Average of radial and tangential
		Inches	*Inches*	*Inches*	*Per cent*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
[1] 30	Structural	7.13	16.05	180	17.7	0.460	4,080	7,220	1,338	1.14	4.85	480	9.8	0.457	6,935	19.0	0.457	978		
	Small, clear	2.00	2.00		8.5	.498	6,237	11,527	1,144	1.92	9.42	410	8.6	.491	7,833	8.4	.503	1,471	9.3	
[1] 31	Structural	8.02	15.99	180	18.5	.389	3,720	5,490	1,347	.93	3.92	393	9.0	.412	4,865	17.8	.382	497		
	Small, clear	2.00	2.00		8.5	.391	5,923	10,163	1,494	1.32	6.48	356	8.4	.386	7,100	8.2	.402	470	9.1	909
[1] 32	Structural	7.90	16.03	180	17.8	.457	4,060	7,360	1,772	.85	3.90	490	10.0	.481	6,940	17.3	.453	570		
	Small, clear	2.00	2.00		8.6	.483	9,576	14,246	2,000	2.46	12.04	500	8.3	.481	9,620	8.7	.479	641	9.1	1,110
[1] 33	Structural	7.65	16.12	180	18.9	.437	4,380	6,580	1,377	1.27	4.16	440	9.6	.445	6,055	18.9	.432	462		
	Small, clear	2.00	2.00		8.5	.447	8,152	12,905	1,747	2.11	8.18	454	8.4	.450	8,512	8.4	.442	571	9.4	1,027
[1] 34	Structural	7.93	16.07	180	17.6	.426	4,600	7,160	1,621	1.19	4.29	477	9.4	.448	7,705	17.2	.436	333		
	Small, clear	2.00	2.00		8.7	.439	8,699	14,408	1,898	2.23	12.17	505	8.1	.441	8,835	8.7	.431	578	9.2	1,162
[1] 35	Structural	8.03	16.22	174	17.8	.423	3,440	5,770	1,430	.76	2.69	401	9.1	.419	7,685	17.5	.409	596		
	Small, clear	2.00	2.00		8.4	.450	7,928	11,758	1,544	2.27	6.53	414	8.3	.458	8,193	8.7	.464	1,103	9.3	1,065
[1] 36	Structural	8.11	15.96	180	18.2	.430	3,730	5,790	1,541	.84	2.31	383	9.8	.450	6,300	18.1	.420	518		
	Small, clear	2.00	2.00		8.5	.443	8,356	11,882	1,768	2.19	7.70	417	8.6	.437	7,958	8.7	.450	697	9.3	1,067
[1] 37	Structural	7.86	15.89	180	17.2	.436	5,290	7,010	1,717	1.49	2.94	462	9.6	.455	8,335	17.6	.410	522		
	Small, clear	2.00	2.00		8.5	.452	8,007	14,777	1,849	1.96	13.39	517	8.1	.459	9,075	8.0	.458	724	9.0	1,310
[1] 38	Structural	8.08	15.92	168	17.1	.438	4,500	6,500	1,405	1.32	3.37	460	9.7	.456	5,220	16.9	.426	781		
	Small, clear	2.00	2.00		8.4	.445	9,017	13,845	1,753	2.60	10.36	486	8.4	.439	8,108	8.1	.447	638	9.4	1,152
[1] 39	Structural	7.77	15.85	180	16.7	.458	4,220	6,760	1,825	.89	2.76	445	9.6	.468	6,950	17.0	.454	528		
	Small, clear	2.00	2.00		8.8	.454	9,973	14,380	2,046	2.74	9.56	505	7.9	.466	9,408	8.2	.476	718	9.0	964
[1] 40	Structural	8.07	16.11	180	17.2	.436	3,470	5,580	1,442	.76	2.43	373	9.6	.450	5,005	17.5	.448	552		
	Small, clear	2.00	2.00		8.6	.437	8,063	12,330	1,684	2.15	8.01	435	8.3	.442	8,162	8.5	.410	625	9.0	1,098
41	Structural	7.92	15.95	180	17.2	.450	4,940	7,110	1,800	1.24	3.25	471	9.4	.461	8,030	17.2	.486	830		
	Small, clear	2.00	2.00		8.6	.485	10,142	16,257	2,162	2.65	15.98	570	7.6	.487	10,348	8.8	.480	611	9.1	1,272
[1] 42	Structural	8.05	16.09	180	18.9	.436	3,530	5,300	1,248	.91	3.02	353	9.8	.426	5,190	19.0	.436	508		
	Small, clear	2.00	2.00		8.8	.466	7,532	12,220	1,629	1.94	10.80	432	8.2	.485	8,512	9.1	.509	723	9.4	1,144
[1] 43	Structural	7.76	16.07	180	18.5	.474	3,980	6,220	1,513	.95	2.94	415	9.6	.490	7,110	18.9	.465	523		
	Small, clear	2.00	2.00		8.5	.515	8,442	14,360	1,796	2.21	11.86	504	8.4	.503	9,078	8.8	.503	1,188	9.6	1,472
44	Structural	7.91	15.99	180	17.4	.441	4,080	6,920	1,747	.87	4.35	459	10.0	.466	7,815	17.7	.460	538		
	Small, clear	2.00	2.00		8.8	.463	10,050	16,000	2,074	2.71	14.15	563	7.6	.460	9,638	8.3	.467	671	9.2	1,191

[1] 45	Structural	8.06	15.91	180	17.3	.446	4,440	6,600	1,771	1.02	2.79	435	10.0	.462	8,005	17.4	.444	581	
	Small, clear	2.00	2.00		8.7	.470	9,807	15,323	2,022	2.66	12.74	538	7.9	.479	9,157	8.7	.475	537	9.8	1,162
[1] 46	Structural	8.78	15.98	180	18.3	.434	4,840	6,250	1,635	1.31	2.60	415	10.0	.456	7,775	18.3	.433	560	
	Small, clear	2.00	2.00		8.3	.466	9,073	14,555	1,915	2.40	11.74	511	7.6	.472	9,635	8.3	.466	620	9.2	1,060
47	Structural	8.24	16.25	180	16.9	.438	3,330	4,870	1,362	.74	1.88	328	9.4	.436	7,175	17.4	.423	571	
	Small, clear	2.00	2.00		8.8	.443	6,548	11,513	1,346	1.80	7.97	405	7.9	.445	7,492	8.3	.470	804	9.4	1,116
[1] 48	Structural	7.84	16.07	180	17.1	.417	4,030	5,460	1,518	.97	2.71	364	9.6	.411	5,870	16.9	.417	467	
	Small, clear	2.00	2.00		8.5	.437	8,425	13,842	1,876	2.10	11.86	487	8.6	.442	7,762	8.8	.458	779	9.0	1,026
[1] 49	Structural	8.04	16.47	180	16.4	.425	3,710	4,130	1,168	1.09	1.41	282	9.6	.437	6,405	17.5	.418	513	
	Small, clear	2.00	2.00		8.4	.429	6,728	10,558	1,311	1.94	6.12	362	8.9	.432	6,938	8.7	.435	724	9.5	1,050
[1] 50	Structural	8.13	16.35	180	16.5	.417	3,590	4,240	1,499	.78	1.21	287	9.6	.424	7,015	17.4	.425	420	
	Small, clear	2.00	2.00		8.2	.416	7,735	11,980	1,660	2.02	7.55	429	8.2	.416	7,423	8.1	.407	722	9.5	1,108
[1] 51	Structural	7.75	16.19	180	16.1	.394	3,790	4,600	1,497	.88	1.42	308	9.0	.426	6,285	16.7	.388	373	
	Small, clear	2.00	2.00		8.5	.408	7,752	12,105	1,705	1.96	8.37	425	8.1	.421	7,840	8.5	.412	589	9.4	890
[1] 52	Structural	8.01	16.27	180	17.4	.420	2,580	4,480	1,439	.42	2.07	301	9.4	.426	6,305	17.6	.434	750	
	Small, clear	2.00	2.00		8.5	.436	8,170	12,110	1,662	2.25	7.43	428	7.8	.458	8,120	8.7	.483	721	9.1	1,106
[1] 53	Structural	7.71	16.10	168	17.4	.519	4,230	6,140	1,723	.95	5.80	439	10.8	.566	8,010	18.1	.508	735	
	Small, clear	2.00	2.00		8.7	.531	10,423	16,898	1,971	3.10	15.58	593	8.7	.544	10,213	8.4	.547	817	9.4	1,200
54	Structural	7.97	16.26	174	17.8	.490	3,460	5,720	1,742	.63	2.06	399	10.4	.534	8,120	18.6	.475	683	
	Small, clear	2.00	2.00		8.6	.519	10,545	15,763	2,349	2.65	11.64	549	7.9	.530	10,828	8.3	.530	931	8.7	1,356
[1] 55	Structural	7.82	16.14	180	17.6	.405	4,000	4,380	1,326	1.10	1.47	293	9.4	.422	6,560	17.3	.404	591	
	Small, clear	2.00	2.00		8.6	.464	7,238	12,080	1,472	1.99	9.55	427	8.2	.480	7,538	8.7	.448	724	9.5	Culled.
[1] 56	Structural	7.98	15.98	180	17.1	.440	3,560	4,710	1,423	.81	1.70	312	9.2	.406	6,895	17.3	.447	596	
	Small, clear	2.00	2.00		8.2	.449	8,618	13,765	1,820	2.28	11.82	488	8.3	.442	8,060	8.3	.452	617	9.2	1,114
[1] 57	Structural	8.02	16.29	180	17.4	.424	2,740	4,120	1,316	.52	1.48	278	10.0	.466	6,380	17.5	.428	777	
	Small, clear	2.00	2.00		8.4	.421	8,543	13,050	1,766	2.32	9.81	443	8.3	.422	7,847	8.4	.420	598	9.2	1,094
[1] 58	Structural	7.76	15.94	180	17.3	.467	3,930	4,190	1,576	.89	4.17	277	9.8	.490	7,340	17.6	.456	592	
	Small, clear	2.00	2.00		8.6	.474	9,192	15,812	1,995	2.36	12.90	545	7.9	.475	9,897	8.2	.473	689	9.1	1,206

[1] This timber contained one or more rotten knots which would not be permissible in structural timbers meeting the requirements of American lumber standards. The depth of rot was not recorded, but if the depth does not exceed the diameter of the knot, the timber may be graded as if the knot were sound, according to the principles of grading in U. S. Dept. Agr. Circ. 295 (*15*). If the depth of rot at a knot exceeds the diameter, the timber would be graded as S4 or a cull by the grading principles of U. S. Dept. Agr. Circ. 295.

TABLE 13.—*Detailed data on the individual structural timbers of green Sitka spruce from Alaska and of small, clear specimens cut from them*

Specimen No.	Type of specimen	Actual cross-section		Span	Static bending								Compression parallel to grain			Compression perpendicular to grain			Shearing strength parallel to grain	
					Moisture content	Specific gravity	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Horizontal shear stress at maximum load	Moisture content	Specific gravity	Maximum crushing strength	Moisture content	Specific gravity	Fiber stress at elastic limit	Moisture content	Average of radial and tangential
		Inches	*Inches*	*Inches*	*Per cent*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
1	Structural	7.90	16.10	180	44.7	0.337	2,180	4,100	1,085	0.40	4.60	273	45.5	0.328	2,165	44.5	0.323	171		
	Small, clear	2.00	2.00		55.1	.325	2,020	4,310	1,044	.23	6.43	153	50.8	.316	1,970	59.4	.324	244	59.9	628
2	Structural	8.20	16.18	180	33.4	.389	3,050	5,500	1,563	.54	8.48	369	37.1	.378	2,875	34.1	.376	214		
	Small, clear	2.00	2.00		37.7	.388	2,800	5,980	1,700	.26	5.88	213	35.9	.382	2,940	36.8	.393	225	35.1	689
3	Structural	8.11	16.11	180	31.7	.332	2,270	4,040	1,260	.38	3.27	270	32.3	.318	2,200	34.7	.325	163		
	Small, clear	2.00	2.00		30.5	.319	2,330	4,480	1,140	.27	4.24	160	30.8	.313	2,270	30.0	.321	274	31.2	576
4	Structural	8.14	16.22	180	40.0	.397	2,550	4,730	1,300	.46	5.49	318	33.7		2,220	52.8	.398	187		
	Small, clear	2.00	2.00		40.7	.356	3,060	5,480	1,188	.46	6.23	196	39.0	.354	2,410	39.7	.352	305	44.1	613
5	Structural	8.30	16.18	180	34.8	.431	2,970	5,150	1,460	.55	3.29	345	35.5	.418	2,960	36.2	.437	222		
	Small, clear	2.00	2.00		33.7	.414	2,100	6,310	1,380	.18	6.47	225	32.4	.413	3,070	34.1	.424	334	29.7	747
6	Structural	8.11	16.01	180	30.5	.341	2,320	4,460	1,335	.36	2.92	296	31.5	.339	2,645	32.2	.342	135		
	Small, clear	2.00	2.00		29.9	.341	2,150	5,480	1,490	.17	6.47	196	31.1	.341	2,680	30.0	.337	232	28.8	688
7	Structural	8.12	16.26	180	30.9	.345	2,540	4,430	1,200	.49	2.49	298	30.4	.352	2,675	31.9	.344	176		
	Small, clear	2.00	2.00		31.5	.354	1,940	5,470	1,513	.14	4.55	196	31.1	.351	2,710	31.4	.358	279	28.9	605
8	Structural	8.08	16.17	180	33.7	.317	2,110	3,890	1,210	.34	2.63	260	32.3	.306	2,185	35.6	.317	206		
	Small, clear	2.00	2.00		31.7	.319	2,490	4,810	1,057	.33	5.33	172	30.3	.319	2,110	31.3	.314	171	32.4	588
9	Structural	8.00	15.87	180	38.2	.393	1,950	4,210	1,125	.30	5.18	276	41.0	.364	2,505	37.0	.363	204		
	Small, clear	2.00	2.00		58.6	.362	2,730	5,200	1,080	.39	6.78	188	55.4	.361	2,420	58.5	.364	344	56.6	726
10	Structural	8.23	16.09	180	31.0	.300	2,740	4,450	1,375	.49	2.19	295	32.2	.378	2,455	31.6	.394	202		
	Small, clear	2.00	2.00		31.1	.391	3,220	5,630	1,330	.44	6.08	200	31.2	.300	2,580	30.7	.381	222	34.8	631
11	Structural	8.33	16.13	180	30.7	.386	2,440	4,270	1,355	.40	2.16	285	32.0	.373	2,690	31.2	.426	167		
	Small, clear	2.00	2.00		34.3	.378	3,020	5,530	1,300	.38	5.87	198	34.3	.374	2,640	31.4	.368	234	33.0	613
12	Structural	8.10	15.93	180	52.7	.425	2,490	4,620	1,090	.51	6.31	304	43.6	.412	3,070	50.4	.408	219		
	Small, clear	2.00	2.00		76.3	.388	2,190	6,080	1,470	.18	7.23	216	68.7	.390	2,670	67.2	.395	389	62.7	752
13	Structural	8.10	16.31	180	31.4	.364	2,370	4,140	1,355	.37	1.98	279	33.3	.368	2,700	32.0	.357	149		
	Small, clear	2.00	2.00		31.6	.358	2,130	5,590	1,315	.20	4.23	196	30.6	.354	2,630	30.6	.360	252	28.4	698
14	Structural	8.15	16.23	180	31.6	.324	1,950	3,630	1,160	.29	2.70	244	31.7	.314	2,305	32.6	.321	149		
	Small, clear	2.00	2.00		30.4	.319	2,400	5,000	1,240	.27	5.90	178	30.2	.318	2,380	31.1	.312	203	27.5	668
15	Structural	7.96	16.24	180	29.0	.351	2,260	3,970	1,210	.38	1.98	266	31.0	.348	2,505	30.2	.336	186		
	Small, clear	2.00	2.00		31.0	.346	2,980	5,500	1,212	.43	5.13	188	30.6	.342	2,690	37.1	.331	237	29.6	661
16	Structural	8.08	15.76	180	31.5	.368	2,270	4,060	1,160	.40	2.50	265	31.5	.352	2,275	32.6	.364	162		
	Small, clear	2.00	2.00		32.8	.369	2,190	5,660	1,364	.20	6.25	202	31.3	.364	2,560	31.8	.368	307	29.3	698

17	Structural	8.10	16.23	180	31.7	.337	2,220	3,790	1,355	.33	2.13	254	37.2	.337	2,655	32.9	.339	173		
	Small, clear	2.00	2.00		30.8	.340	2,560	5,440	1,420	.27	5.83	194	30.7	.336	2,700	30.3	.341	249	31.1	662
18	Structural	8.32	16.51	180	32.2	.345	1,970	3,770	1,245	.28	2.25	258	33.3	.349	2,420	32.2	.370	181		
	Small, clear	2.00	2.00		30.9	.343	2,100	5,450	1,313	.19	5.23	195	29.6	.346	2,690	29.2	.344	251	27.8	705
19	Structural	8.06	16.22	180	32.2	.328	1,810	3,330	1,008	.27	1.66	223	39.9	.322	2,245	35.0	.328	173		
	Small, clear	2.00	2.00		31.8	.319	1,910	4,860	1,170	.18	4.32	176	30.9	.318	2,270	30.5	.331	250	28.2	529
20	Structural	8.19	16.22	180	33.1	.340	1,410	2,700	1,125	.16	1.04	181	34.2	.332	2,360	34.8	.345	218		
	Small, clear	2.00	2.00		33.2	.335	2,480	4,810	1,050	.33	4.58	172	31.7	.332	2,260	31.6	.329	241	34.3	559

TABLE 14.—*Detailed data on individual structural timbers of air-dry Sitka spruce from Alaska and of small, clear specimens cut from them*

Specimen No.	Type of specimen	Actual cross-section		Span	Static bending								Compression parallel to grain			Compression perpendicular to grain			Shearing strength parallel to grain	
					Moisture content	Specific gravity	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Horizontal shear stress at maximum load	Moisture content	Specific gravity	Maximum crushing strength	Moisture content	Specific gravity	Fiber stress at elastic limit	Moisture content	Average of radial and tangential
		Inches	*Inches*	*Inches*	*Per cent*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
21	Structural	7.90	15.67	180	14.4	0.385	3,920	6,390	1,520	0.93	6.02	417	15.5	0.390	4,770	15.6	0.374	262		
	Small, clear	2.00	2.00		14.5	.371	4,780	8,390	1,517	.84	9.84	299	13.4	.368	5,000	15.2	.366	330	15.5	832
22	Structural	7.68	15.43	180	14.6	.425	4,020	6,920	1,620	.91	3.83	443	15.2	.400	5,080	15.8	.422	415		
	Small, clear	2.00	2.00		14.3	.414	5,120	9,440	1,660	.89	11.30	337	13.2	.404	5,080	15.2	.399	453	13.4	867
23	Structural	8.12	15.96	180	14.7	.384	3,760	5,760	1,245	1.04	2.91	381	15.4	.387	4,620	14.8	.388	507		
	Small, clear	2.00	2.00		14.4	.381	4,820	8,050	1,275	1.02	9.25	287	14.0	.368	4,160	15.0	.348	360	12.6	789
24	Structural	7.99	15.64	180	14.6	.374	4,860	5,780	1,350	1.61	3.75	375	14.4	.378	4,250	15.5	.375	521		
	Small, clear	2.00	2.00		14.9	.369	5,080	8,090	1,323	1.09	7.06	288	13.9	.374	4,430	15.8	.376	535	13.1	726
25	Structural	7.96	15.48	180	16.0	.412	4,650	7,120	1,610	1.23	7.68	457				15.8	.412	602		
	Small, clear	2.00	2.00		14.7	.414	5,780	10,330	1,828	1.02	11.68	369	14.4	.420	5,540	15.4	.420	577	13.4	784
26	Structural	7.86	15.87	180	19.8	.334	3,660	4,880	1,215	1.01	4.80	322	10.2	.376	5,530	15.9	.332	428		
	Small, clear	2.00	2.00		13.2	.318	4,590	7,250	1,121	1.05	6.46	259	12.1	.321	4,610	11.2	.346	410	11.8	825
27	Structural	8.04	15.49	180	16.3	.396	4,270	5,600	1,475	1.13	2.25	360	14.9	.399	4,350	16.0	.402	473		
	Small, clear	2.00	2.00		15.5	.396	5,160	8,600	1,404	1.06	11.08	306	14.9	.403	4,840	15.5	.404	583	13.7	826
28	Structural	7.92	15.69	180	14.2	.335	3,250	4,580	1,250	.77	1.87	299	15.7	.319	3,840	16.1	.322	489		
	Small, clear	2.00	2.00		16.0	.322	4,220	7,100	1,208	.83	7.54	253	14.5	.323	3,970	14.7	.321	345	12.6	697
29	Structural	8.04	15.55	180	15.7	.359	4,560	5,500	1,415	1.35	2.24	356	15.1	.351	4,600	15.2	.374	469		
	Small, clear	2.00	2.00		14.8	.363	5,240	8,400	1,386	1.12	9.42	300	14.3	.352	4,660	15.3	.367	387	13.9	682
30	Structural	7.92	15.42	180	15.0	.372	3,750	5,670	1,635	.79	2.26	364	15.2	.370	5,120	15.4	.374	352		
	Small, clear	2.00	2.00		14.9	.378	5,130	9,050	1,622	.91	10.13	323	13.9	.376	5,120	15.1	.380	373	12.9	699
31	Structural	7.84	15.73	180	15.0	.346	3,730	4,640	1,205	1.06	1.81	304	14.9	.332	4,310	14.4	.345	527		
	Small, clear	2.00	2.00		14.1	.340	4,390	7,410	1,349	.80	8.34	266	13.4	.343	4,150	14.3	.353	312	14.1	703

TABLE 14.—*Detailed data on individual structural timbers of air-dry Sitka spruce from Alaska and of small, clear specimens cut from them*—Con.

Specimen No.	Type of specimen	Actual cross-section		Span	Static bending								Compression parallel to grain			Compression perpendicular to grain			Shearing strength parallel to grain	
					Moisture content	Specific gravity	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Horizontal shear stress at maximum load	Moisture content	Specific gravity	Maximum crushing strength	Moisture content	Specific gravity	Fiber stress at elastic limit	Moisture content	Average of radial and tangential
		Inches	*Inches*	*Inches*	*Per cent*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*		*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
32	Structural	8.25	15.97	180	20.9	0.410	4,090	6,020	1,720	0.89	2.75	398	16.0	0.415	4,970	16.3	0.419	249		
	Small, clear	2.00	2.00		14.6	.401	6,250	9,720	1,663	1.31	13.89	347	13.6	.396	5,590	11.4	.405	515	12.0	1,031
33	Structural	8.05	15.68	180	22.0	.457	5,020	7,010	1,770	1.31	3.33	457	16.2	.477	5,790	13.1	.503	745		
	Small, clear	2.00	2.00		14.7	.458	6,830	11,330	1,654	1.57	15.27	404	12.9	.444	6,200	12.9	.492	685	12.1	1,316
34	Structural	8.01	15.68	180	19.2	.332	3,040	4,620	1,300	.65	2.00	302	15.2	.330	4,150					
	Small, clear	2.00	2.00		14.8	.328	4,670	7,580	1,219	1.00	7.69	270	11.8	.335	4,740	12.1	.335	442	12.6	902
35	Structural	8.28	16.01	180	23.2	.368	3,330	4,530	1,270	.80	2.26	302	15.6	.361	4,190					
	Small, clear	2.00	2.00		14.1	.370	4,950	7,810	1,122	1.23	6.61	278	12.1	.379	4,880	11.8	.364	477	11.0	1,000
36	Structural	8.20	16.09	180	19.7	.337	2,950	4,350	1,070	.74	2.27	290	14.9	.336	3,890	11.5	.346	399		
	Small, clear	2.00	2.00		14.4	.348	5,020	7,620	1,290	1.09	4.88	272	12.1	.349	4,960	11.5	.358	639	11.5	854
37	Structural	8.16	16.30	180	14.6	.357	3,880	4,860	1,265	1.09	2.25	330	15.0	.345	4,150	14.8	.350	387		
	Small, clear	2.00	2.00		14.2	.398	4,940	8,740	1,246	1.10	9.80	311	13.9	.384	4,500	15.4	.405	587	12.8	853
38	Structural	7.97	15.84	180	15.2	.348	3,220	4,450	1,375	.69	1.42	293	14.4	.342	4,420	15.5	.341	375		
	Small, clear	2.00	2.00		14.5	.337	4,760	8,240	1,408	.88	10.20	294	14.0	.335	4,530	15.2	.336	403	13.7	659
39	Structural	7.99	15.86	180	19.9	.368	3,160	3,890	1,490	.61	.99	255				15.0	.365	368		
	Small, clear	2.00	2.00		14.2	.380	5,500	8,050	1,481	1.14	5.11	288	13.5	.374	4,960	11.1	.357	510	11.0	990
40	Structural	7.89	16.22	180	20.3	.354	2,840	3,650	1,175	.63	1.02	246	14.7	.364	4,010	14.9	.362	425		
	Small, clear	2.00	2.00		14.5	.353	5,270	8,230	1,382	1.12	8.12	293	12.1	.352	5,240	11.1	.363	467	12.0	860

The allowable safe stress in bending recommended by the Forest Products Laboratory for western hemlock is 1,300 pounds per square inch for the Select grade for all thicknesses used under continuously dry conditions. This fact would establish 3,900 pounds per square inch as a desirable minimum value of modulus of rupture of western hemlock under test conditions for a select grade. Tables 11 and 15 show that the poorest western hemlock timber (No. 26), which might be graded as Select or S2, developed under test a modulus of rupture (3,950 pounds per square inch) just within the limits considered a desirable minimum.

These timbers, when tested were graded by the rules of the Pacific Lumber Inspection Bureau, which, however, did not include all the principles of strength grading. They were also originally graded according to the Forest Service rules set forth in Forest Service Bulletin 108 (*6*). These rules have since been superseded by the basic grades proposed in Department Circular 295 (*15*), on which the present American lumber standards grades of Select and Common are based (*22*). It was thought preferable, in connection with the individual structural timbers, to regrade them so far as possible in accordance with the latest principles and rules.

The results of this regrading, which followed the principles of Department Circular 295 (*15*), are presented in Tables 15 to 18. Unfortunately, the records of defects and their location are not complete enough to permit, in all cases, and several years after the tests were made, of accurate and final grading, particularly with respect to cross grain, checks, shakes, and decay. The grading given in the tables for each face, therefore, is that based on knots alone. In some cases it is known that other defects than knots controlled the strength, nevertheless, it is felt that the grading on the basis of knots alone is of considerable value in indicating the character of the material.

TABLE 15.—*Classification of green western hemlock structural timbers according to grade*

[The letters *a*, *b*, *c*, and *d* denote the successive faces of the timbers (clockwise) when viewed from the butt end]

Specimen No.	Grade [1] of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
1	S1; clear	S1; clear	S2; 1½-inch sound knot at center of length of beam and about 2 inches from bottom edge.	S1; 1½-inch sound knot at center of length of beam and 7 inches from top edge.	Compression, tension, compression, tension.
2	S1; 1-inch rotten knot 31 inches from center of length of beam and 3 inches from edge.	do	S1; clear	S1; 1¼-inch sound knot 37 inches from center of length of beam and 7 inches from top edge.	Compression, splintering tension.
3	S1; 1¼-inch sound knot 37 inches from center and 2 inches from edge.	do	S1; 1-inch sound knot 12 inches from center of length of beam and 6½ inches from bottom edge.	S1; 1½-inch rotten knot 22 inches from center of length of beam and 4 inches from top edge.	Compression, spiral grain tension, horizontal shear.
4	S1; clear	do	S2; 1-inch sound knot 24 inches from center of length of beam and 3 inches from bottom edge.	S1; clear	Slight spiral grain tension, horizontal shear.
5	do	do	S1; ¾-inch sound knot 6 inches from center of length of beam and 11 inches from bottom edge.	do	Compression, slight spiral grain tension, splintering tension and horizontal shear.
6	S2; 1½-inch rotten knot 11 inches from center of length of beam and 4 inches from edge.	do	S2; 2-inch sound knot 8 inches from center of length of beam and 4 inches from top edge.	S1; 1¼-inch sound knot 6 inches from center of length of beam and 5 inches from top edge.	Compression, spiral grain tension, horizontal shear.
7	S1; clear	do	S1; 1-inch sound knot 5 inches from center of length of beam near top edge.	S1; clear	Compression, splintering tension.
8	do	do	S2; 2-inch sound knot 31 inches from center of length of beam and 6 inches from bottom edge; 2-inch sound knot 40 inches from center of length of beam and 4 inches from top edge.	S1; 1-inch sound knot 15 inches from center of length of beam and 2 inches from edge.	Compression, splintering tension, brash and splintering tension.
9	S1; small bark pocket 14 inches from center at edge.	do	S1; clear	S2; 2-inch sound knot 13½ inches from center of length of beam and 2 inches from top edge; 2-inch rotten knot 28 inches from center of length of beam and 4¾ inches from bottom edge.	Compression and brash tension.

[1] S1, S2, S3, and S4 designate grades of timbers representing 87½, 75, 62½, and 50 per cent, respectively, of the strength of the clear wood (U. S. Dept. Agr. Cir. 295).

10	S3; 2-inch sound knot 21 inches from center of length of beam and at edge.	S1; clear with some wane at end.	----do----	S3; 2-inch sound knot 21 inches from center of length of beam and at top edge.	Compression, brash tension.
11	S2; about 1¼-inch sound knot 36 inches from center of length of beam and at the edge.	S2; about 1¾-inch sound knot 22 inches from center of length of beam and 3 inches from edge.	S2; 2-inch sound knot 36 inches from center of length of beam and extends to top edge.	S1; 1-inch sound knot 15 inches from center of length of beam and about 1 inch from bottom edge.	Brash tension.
12	S1; 1-inch rotten knot 16 inches from center of length of beam and 1½ inches from edge; 1-inch rotten knot 6 inches from center of length of beam and 5 inches from edge.	S1; clear----	S1; clear except for 1 by 3 inch spike knot near support.	S2; 2-inch sound knot 15½ inches from center of length of beam and 2 inches from top edge.	Compression, simple tension.
13	S2; 1½-inch rotten knot 12 inches from center of length of beam and at edge.	S1; bark streak 1½ inches wide--	S2; 1½-inch rotten knot 12 inches from center of length of beam and at top edge.	S2; 1½-inch sound knot 32 inches from center of length of beam at top edge.	Compression, simple tension, simple tension.
14	S1; clear----	S1; clear----	S1; clear----	S2; 1½-inch sound knot 27½ inches from center of length of beam and 2 inches from top edge.	Compression, spiral grain tension, horizontal shear.
15	----do----	S1; clear except for pitch seam 12 inches long beginning 30 inches from center of length of beam.	S1; 2-inch sound knot 4 inches from center of length of beam and 7 inches from bottom edge.	S1; clear----	Spiral grain tension, horizontal shear, buckling.
16	----do----	S1; 1-inch rotten knot 26 inches from center of length of beam and 1 inch from edge.	S1; 1-inch sound knot 27½ inches from center of length of beam and 2 inches from bottom edge.	----do----	Compression, spiral grain tension, horizontal shear.
17	----do----	S1; clear but shows some wane at end.	S1; 1-inch sound knot 38 inches from center of length of beam and 4 inches from bottom edge.	----do----	Slight tension, spiral grain tension and horizontal shear.
18	S1; any of three 1-inch sound knots, 25, 23, and 2 inches respectively from center of length of beam.	S1; clear except ½ by 18 inch bark streak beginning 4½ inches from center of length of beam.	S1; 1¼-inch sound knot 45 inches from center of length of beam and 9 inches from bottom edge; considerable bark.	S1; 1¼-inch sound knot 18 inches from center of length of beam and 3 inches from top edge.	Compression, spiral-grain tension and horizontal shear.
19	S1; 1-inch rotten knot 38 inches from center of length of beam and 1½ inches from edge.	S1; ¾-inch rotten knot 38½ inches from center of length of beam about 3 inches from edge.	S2; 2-inch rotten knot 30 inches from center of length of beam and 6½ inches from top edge.	S2; 1-inch sound knot 24 inches from center of length of beam at top edge.	Horizontal shear and brash tension.
20	S1; clear----	S1; clear----	S2; 2-inch sound knot 8 inches from center of length of beam and about 4 inches from upper edge.	S1; clear----	Compression, horizontal shear, spiral-grain tension.
21	S3; 2-inch sound knot 11 inches from center of length of beam and 4 inches from edge.	----do----	S3; 2½-inch sound knot 7 inches, from center of length of beam and 1 inch from top edge.	----do----	Cross-grain tension, horizontal shear, brash tension.
22	S1; clear----	S1; clear but shows some wane near center.	S1; 1-inch sound knot 3 inches from center of length of beam and 5 inches from top edge.	S1; clear but shows some wane near center.	Spiral-grain tension, compression, buckling and splitting.

TABLE 15.—*Classification of green western hemlock structural timbers according to grade*—Continued

Specimen No.	Grade of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
23	S1; 1-inch sound knot 8½ inches from center of length of beam and at edge; 1-inch sound knot 6 inches from center of length of beam and 1 inch from edge.	S1; bark streak 2 inches wide.	S1; 1-inch rotten knot 30 inches from center of length of beam and 7⅜ inches from top edge; 1-inch sound knot 11 inches from center of length of beam and 5½ inches from bottom edge.	S1; 1-inch sound knot 8½ inches from center of length of beam and at top edge.	Compression, brash tension and simple tension.
24	S1; 1-inch sound knot 28 inches from center of length of beam and 1 inch from edge.	S1; clear	S1; 1¼-inch sound knot 5 inches from center of length of beam and 4½ inches from top edge.	S1; clear	Horizontal shear, brash tension.
25	S2; 1½-inch sound knot 38 inches from center of length of beam and 1 inch from edge.	S1; bark streak 1 inch wide by 30 inches long beginning 34 inches from center of length to beam.	S2; 1¼-inch sound knot 22 inches from center of length of beam and at top edge, also bark streaks.	S1; several bark streaks [3]	Horizontal shear.
26	S1; 1-inch sound knot 5 inches from center of length of beam and at the edge; 1-inch sound knot 24 inches from center of length of beam and at the edge.	S2; 1¼-inch sound knot at center of length of beam and 2 inches from edge.	S2; 1⅝-inch sound knot 9 inches from center of length of beam and 2½ inches from bottom edge.	S1; 1-inch sound knot 6 inches from center of length of beam and 5 inches from top.[5]	Horizontal shear, simple tension.
27	S2; 1¼-inch sound knot 36½ inches from center of length of beam and at edge.	S2; 1½-inch sound knot 39 inches from center of length of beam and 3 inches from edge.	S2; 1½-inch sound knot 37 inches from center of length of beam and 2 inches from bottom edge.	S1; 1-inch sound knot 43 inches from center of length of beam and 3 inches from top edge.	Compression, horizontal shear, spiral-grain tension.
28	S1; clear	S1; clear with some wane at end	S1; clear but some wane at end	S3; 2-inch bark knot 19 inches from center of length of beam and 1 inch from top edge.[4]	Horizontal shear, brash tension.
29	do	S1; clear	S2; 3-inch sound knot 1 inch from center of length of beam and 7 inches from bottom edge.	S1; clear except for a 1-inch sound knot 92 inches from center of length of beam.[5]	Slight spiral-grain tension, buckling, compression, horizontal shear.

[2] A rotten knot and checks would probably make this timber unacceptable in any strength grade.
[3] Probably contained some shake, but not recorded.
[4] Serious decay would make this timber unacceptable in any strength grade.
[5] Rotten knots, checks, and cross grain would make this timber unacceptable in the S2 grade.

TABLE 16.—*Classification of air-dry western hemlock structural timbers according to grade*

[The letters *a*, *b*, *c*, and *d* denote the successive faces of the timbers (clockwise) when viewed from the butt end]

Specimen No.	Grade [1] of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
30	S1; 1-inch rotten knot 19 inches from center of length of beam and at edge.	S1; ¾-inch rotten knot 12 inches from center of length of beam and 2 inches from edge.	S1; 1-inch sound knot 19 inches from center of length of beam and 12 inches from top edge.	S1; 1-inch rotten knot 19 inches from center of length of beam and at top edge.	Horizontal shear, brash tension, splintering tension.
31	S2; 1¼-inch rotten knot 32 inches from center of length of beam and at edge.	S1; clear except for 2-inch sound knot 72 inches from center of length of beam and 6 inches from edge.	S2; 2-inch rotten knot 40 inches from center of length of beam and at top edge.	S2; 2-inch sound knot 43 inches from center of length of beam and 3 inches from bottom edge.	Slight spiral grain tension, horizontal shear, spiral grain and splintering tension.
32	S1; clear but contains large amount of advanced decay.	S1; clear	S1; clear but shows some checks and wane.	S1; 1-inch rotten knot 24 inches from center of length of beam and near top edge.	Buckling; horizontal shear, spiral grain tension; compression at probably 70,000 pounds total load.
33	S2; 2-inch sound knot 40 inches from center of length of beam and 6½ inches from edge.	S1; clear but contains some checks.	S1; 1-inch sound knot 19 inches from center of length of beam and 7 inches from top edge.	S3; 2½-inch sound knot 32 inches from center of length of beam and at top edge.	Horizontal shear, slight spiral grain tension, and splintering tension.
34	S2; about 1½-inch sound knot 36 inches from center of length of beam and at edge.	S1; clear	S2; 1½-inch sound knot 6 inches from center of length of beam and extending to within 1 inch of upper edge.	S2; about a 2-inch sound knot 36 inches from center of length of beam and at top edge.	Irregular grain tension, compression, horizontal shear and brash tension.
35	S1; clear but contains some checks.	S1; clear but contains some checks.	S1; contains streak of well advanced decay 2½ inches wide and 76 inches long.	S1; 1-inch sound knot about 18 inches from center of length of beam and 10 inches from bottom edge.	Diagonal grain tension.
36	S1; 1-inch sound knot 22 inches from center of length of beam and 4 inches from edge.	S1; clear but contains some wane and checks.	S3; 4-inch sound knot 44 inches from center of length of beam and about 2 inches from top edge; 3½-inch sound knot 28 inches from center of length of beam and 3 inches from top edge.	S2; 2-inch sound knot 40 inches from center of length of beam and about 5 inches from bottom edge; also check and wane.	Horizontal shear, brash tension and slight compression.
37	S1; clear	S1; clear	S2; 2-inch rotten knot 28 inches from center of length of beam and 6 inches from top edge.	S1; clear but shows some checks	Horizontal shear.
38	S3; 2½-inch sound knot 4 inches from center of length of beam at edge.	do	S1; 1-inch sound knot 2½ inches from center of length of beam about 3 inches from top edge.	S1; ½-inch rotten knot 29 inches from center of length of beam and 13 inches from bottom edge.	Do.

[1] S1, S2, S3, and S4 designate grades of timbers representing 87½, 75, 62½, and 50 per cent, respectively, of the strength of the clear wood (U. S. Dept. Agr. Circ. 295).

TABLE 16.—*Classification of air-dry western hemlock structural timbers according to grade*—Continued

Specimen No.	Grade of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
39	S1; clear but shows some checks.	S1; clear but shows some checks.	S2; 2-inch rotten knot 18 inches from center of length of beam and 3 inches from top edge.	S1; 1½-inch sound knot 20 inches from center of length of beam and 9 inches from bottom edge.	Horizontal shear and slight spiral grain tension.
40	S3; 2-inch rotten knot 24 inches from center of length of beam and 2 inches from edge.	S1; clear except for two knots outside of center half of length.	S2; 1½-inch sound knot 29 inches from center of length of beam and about 1½ inches from top edge.	S1; 2-inch sound knot 10 inches from center of length of beam and 8 inches from bottom edge.	Slight spiral grain and brash tension.
41	S1; clear	S1; clear but shows checks	S2; 2-inch sound knot 42 inches from center of length of beam and 3½ inches from top edge.	S1; clear but shows some checks.	Horizontal shear.
42	S2; 1½-inch sound knot 17 inches from center of length of beam and 2 inches from edge.	S2; about a 1¼-inch sound knot about 18 inches from center of length of beam and 3 inches from edge.	S1; 1-inch spike knot 30 inches from center of length of beam and extending to top face.	S2; 2-inch sound knot 21 inches from center of length of beam and 2 inches from top edge.	Slight tension, brash and simple tension, slight compression.
43	S2; 1½-inch sound knot 3 inches from center of length of beam and 7 inches from edge.	S1; clear but contains some bark streaks and checks.	S2; 2-inch sound knot 6 inches from center of length of beam and 3 inches from top edge.	S2; 1½-inch sound knot 24 inches from center of length of beam and at top edge.	Horizontal shear, brash and splintering tension.
44	S1; clear	S1; clear	S2; 2¼-inch sound knot 7 inches from center of length of beam and extending to bottom edge.	S1; ¾-inch encased knot 25 inches from center of length of beam and 5 inches from top edge.	Irregular grain tension, compression and buckling, horizontal shear.
45	S1; clear except shows some checks.	S1; clear except shows some checks.	S2; 2-inch sound knot 45 inches from center of length of beam and 2 inches from bottom edge.	S1; clear but shows some checks.	Horizontal shear.
46	S1; clear	S1; clear but shows some wane.	S1; 2-inch sound knot 44 inches from center of length of beam and 9 inches from top edge.	S1; clear but contains some checks and wane.	Horizontal shear, spiral grain tension.
47	S1; clear but shows some bark streak near end.	S1; clear	S1; clear but shows some checks.	S2; 2-inch sound knot 35 inches from center of length of beam and 13 inches from bottom edge.	Horizontal shear.
48	S1; 1-inch rotten knot 5 inches from center of length of beam and 1 inch from edge; 1-inch rotten knot 19 inches from center of length of beam and 4 inches from edge.	S3; 3-inch burl 60 inches from center of length of beam and 4½ inches from edge.	S2; 2-inch sound knot 19 inches from center of length of beam and 5 inches from bottom edge.	S2; 1-inch rotten knot 33 inches from center of length of beam and at top edge.	Horizontal shear, splintering tension.
49	S3; 3-inch sound knot 38 inches from center of length of beam and 4 inches from edge.	S3; 2-inch rotten knot 31 inches from center of length of beam and at edge.	S3; 2-inch rotten knot 31 inches from center of length of beam and at bottom edge.	S2; 1½ inch sound knot 22 inches from center of length of beam and 2 inches from top edge.	Brash and diagonal grain tension.

50	S2; 1½-inch rotten knot 40 inches from center of length of beam and 5½ inches from edge; checks.	S1; clear	S2; 2-inch sound knot 22 inches from center of length of beam 6½ inches from top edge.	S1; 1½-inch sound knot 37 inches from center of length of beam and 7 inches from bottom edge.	Horizontal shear, further development of horizontal shear, brash tension.
51	S1; clear except for bark streak at outer third.	do	S1; clear except for 1-inch rotten knot 65 inches from center and checks.	S1; 1-inch sound knot 34 inches from center of length of beam and 10 inches from bottom edge.	Horizontal shear, spiral grain tension.
52	S1; clear	S1; clear except 1-inch rotten knot near end.	S1; 1½-inch sound knot 18 inches from center of length of beam and extending to within 1 inch of top edge.	S1; 1-inch rotten knot 41 inches from center of length of beam and 8 inches from edge.	Horizontal shear, horizontal shear and brash tension.
53	do	S1; clear	S1; 1-inch sound knot 31 inches from center of length of beam and 11 inches from top face; checks.	S2; shake	Horizontal shear, further development of horizontal shear and buckling, irregular grain tension.
54	S1; clear except it shows some checks and wane.	S1; clear but shows some wane	S2; about 2½-inch sound knot 25 inches from center of length of beam and 9 inches from top edge.	S1; clear but contains some checks and wane.	Horizontal shear, horizontal shear in top half, spiral grain tension.
55	S1; clear except for 1-inch rotten knot near end.	S1; clear	S1; clear except for 1½-inch rotten knot 9 inches from top edge near end.	S1; 1-inch sound knot 22 inches from center of length of beam and 4 inches from bottom edge.	Diagonal grain tension.
56	S2; 1¼-inch sound knot 39 inches from center of length of beam 7 inches from edge.	S1; checks and bark	S3; 4-inch sound knot 14 inches from center of length of beam and about 2 inches from top edge; checks.	S1; 1-inch sound knot 24 inches from center of length of beam and 10 inches from bottom edge; checks.	Horizontal shear, spiral grain tension, compression, brash tension in portion above shear failure.
57	S3; 2-inch sound knot 3 inches from center of length of beam and 6 inches from edge.	S1; clear	S2; 2-inch sound knot 27 inches from center of length of beam and 12 inches from top edge.	S1;1-inch sound knot 7 inches from center of length of beam and 13 inches from bottom edge.	Brash and spiral grain tension.
58	S2; 1½-inch sound knot 5 inches from center of length of beam and near edge.	S2; 1½-inch rotten knot 36 inches from center of length of beam and near edge.	S2; 2½-inch sound knot 4 inches from center of length of beam and about 5 inches from top edge.	S2; 1½-inch sound knot 33 inches from center of length of beam and at top edge.	Spiral grain tension, horizontal shear, splintering tension.

TABLE 17.—*Classification of green Sitka spruce structural timbers according to grade*

[The letters *a*, *b*, *c*, and *d* denote the successive faces of the timbers (clockwise) when viewed from the butt end]

Specimen No.	Grade [1] of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
1	S1; clear	S1; clear	S1; clear	S1; clear	Heavy compression, brash and spiral-grained tension.
2	do	do	S1; 1½-inch sound knot 30 inches from center of length of beam, 7 inches from top edge.	do	Heavy compression at four places and slight compression at another place.
3	S1; 1-inch sound knot 35 inches from center at edge.	do	S1; ½-inch sound knot 38 inches from center, 3 inches from bottom.	S1; 1½-inch sound knot 18 inches from center, 8 inches from bottom.	Compression, brash and simple tension.
4	S1; clear	do	S1; clear	S1; clear	Compression, simple tension.
5	do	do	do	do	Compression, spiral tension.
6	do	do	S1; 1½-inch sound knot 40 inches from center, 4 inches from bottom.	do	Compression, spiral-grained tension and horizontal shear.
7	do	do	S1; clear	do	Compression, horizontal shear and brash and spiral-grained tension.
8	S1; ¾-inch sound knot 1 inch from center and 1 inch from edge.	do	S1; 1-inch sound knot 64 inches from center and 4 inches from bottom.	S1; 1½-inch sound knot 10 inches from center, 4 inches from top.	Compression, brash and spiral-grained tension.
9	S1; clear	do	S1; clear	S1; clear	Compression, brash and simple tension.
10	S1; ¾-inch sound knot 11 inches from center and 1 inch from edge.	do	S1; 1-inch sound knot 40 inches from center, 7 inches from bottom.	S1; 1½-inch sound knot 11 inches from center, 8 inches from bottom.	Compression, horizontal shear.
11	S1; 1-inch sound knot 43 inches from center and 4 inches from edge.	S2; 1½-inch sound knot 13 inches from center and 3 inches from edge.	S1; 1½-inch sound knot 23 inches from center, 4 inches from bottom.	S1; 1-inch sound knot 24 inches from center, 7 inches from bottom.	Compression, brash and simple tension, horizontal shear.
12	S1; clear	S1; clear	S1; clear	S1; clear	Heavy compression, compression, splintering tension.
13	S1; 1½-inch sound knot 53 inches from center and 1 inch from edge.	S1; 1-inch sound knot 31 inches from center and 1 inch from edge.	S1; 1½-inch sound knot 31 inches from center, 2 inches from top.	S1; 1½-inch sound knot 12 inches from center, 6 inches from bottom.	Compression, brash and simple tension.
14	S1; clear	S1; clear	S1; clear	S1; clear	Compression, horizontal shear, spiral-grained tension.
15	S1; ½-inch sound knot 19 inches from center at edge	do	S1; ½-inch sound knot 19 inches from center at upper edge; ½-inch sound knot 12 inches from center and 6 inches from top.	do	Compression, simple tension, horizontal shear.

16	S1, 2½-inch sound knot 6 inches from center and 2 inches from edge.	do	S1; 1½-inch spike knot 8 inches from center, 1 inch from top edge.	do	Compression, horizontal shear along wind shake.
17	S1; clear	do	S1; clear	do	Compression, slight spiral-grained tension, horizontal shear.
18	do	do	S1; ½-inch sound knot 26 inches from center, 4 inches from bottom.	do	Compression, horizontal shear and brash and spiral tension.
19	S2; 2-inch sound knot 16 inches from center and 4 inches from edge.	do	S1; 2½-inch sound knot 67 inches from center and at edge.	S1; 1½-inch sound knot 26 inches from center, 4 inches from bottom; 2-inch sound knot 50 inches from center and 1 inch from top.	Compression, brash and spiral tension.
20	S1; clear	S2; about 1½-inch knot 36 inches from center and about 1¼ inches from edge.	S2; 2-inch sound knot 2 inches from center, 6 inches from top edge.	S1; 2-inch sound knot 2 inches from center, 7 inches from top.[2]	Horizontal shear and spiral-grained tension; spiral-grained tension; compression.

[1] S1, S2, S3, and S4 designate grades of timbers representing 87½, 75, 62½, and 50 per cent, respectively, of the strength of the clear wood. (U. S. Dept. Agr. Circ. 295.)
[2] Spiral grain of 1 in 4 would make this timber unacceptable in any of the structural grades.

TABLE 18.—*Classification of air-dry Sitka spruce structural timbers according to grade*

[The letters *a*, *b*, *c*, and *d* denote the successive faces of the timbers (clockwise) when viewed from the butt end]

Specimen No.	Grade [1] of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
21	S2; 2½-inch sound knot 71 inches from center and about 2¼ inches from edge.	S1; clear	S1; clear	S2; 1½-inch sound knot 36 inches from center and about 2½ inches from top edge.	Buckling, splitting and compression; simple tension; compression; brash and simple tension.
22	S1; 1½-inch sound knot 56 inches from center and at edge.	do	S1; 1½-inch sound knot 33 inches from center and about 4½ inches from top.	S1; 2-inch sound knot 51 inches from center and 2½ inches from top edge.	Spiral grain tension; slight compression under load block.
23	S1; clear	do	S1; clear	S1; clear	Horizontal shear, brash tension.
24	do	do	do	do	Compression, brash and spiral-grained tension.
25	S2; 1½-inch sound knot 20 inches from center and 1½ inches from edge.	do	S1; 2-inch sound knot 45 inches from center and at top edge.	do	Compression; splintering and spiral-grained tension.

[1] S1, S2, S3, and S4 designate grades of timber representing 87½, 75, 62½, and 50 per cent, respectively, of the strength of the clear wood (U. S. Dept. Agr. Circ. 295).

TABLE 18.—*Classification of air-dry Sitka spruce structural timbers according to grade*—Continued

Specimen No.	Grade of each face as determined by knots and size and location of limiting knot				Character of failure in bending in order of occurrence
	Upper face (*a*)	Lower face (*c*)	Side face (*b*)	Side face (*d*)	
26	S1; ½-inch sound knot 11 inches from center and 2 inches from edge; ½-inch sound knot 26 inches from center and 1 inch from edge.	S1; ½-inch sound knot 35 inches from center and 3 inches from edge.	S1; 1-inch sound knot 19 inches from center and 6 inches from top.	S1; 1-inch sound knot 26 inches from center and 5 inches from top.	Compression, simple tension, compression, simple tension.
27	S1; clear	S1; clear	S1; clear	S1; clear	Horizontal shear.
28	do	do	S1; 1½-inch loose knot 57 inches from center and 2½ inches from bottom edge.	S1; 1-inch sound knot 31 inches from center and 2 inches from bottom edge.	Brash tension, slight compression, splitting.
29	do	do	S1; clear	S1; clear	Horizontal shear.
30	do	do	do	do	Horizontal shear, slight tension.
31	S1; ½-inch sound knot 16 inches from center near edge.	do	S1; 1-inch sound knot 16 inches from center, ½ inch from top edge.	do	Compression, splitting and simple tension.
32	S1; clear	do	S1; 1-inch sound knot 12 inches from center, 2 inches from bottom.	do	Horizontal shear.
33	do	do	S1; clear	do	Compression, horizontal shear.
34	do	do	S1; 1-inch sound knot 38 inches from center, 6 inches from top edge.	S1; 1-inch sound knot 17 inches from center, 6 inches from bottom edge.	Horizontal shear.
35	do	do	S1; clear	S1; clear	Brash tension.
36	S2; 1½-inch sound knot 30 inches from center at edge.	S2; 2-inch sound knot 51 inches from center near edge.	S1; 1½-inch sound knot 26 inches from center, 4 inches from edge.	S1; 1-inch sound knot 32 inches from center at top edge.	Compression, horizontal shear and diagonal-grained tension.
37	S1; 1-inch sound knot 30 inches from center and 2 inches from edge.	S1; 1½-inch sound knot, 72 inches from center and at edge.	S1; ½-inch loose knot 53 inches from center, 6 inches from bottom edge.	S1; 1-inch loose knot 12½ inches from center and 2½ inches from top edge.	Tension, compression, splintering tension.
38	S3; 2-inch knot 30 inches from center near edge.	S2; 2-inch sound knot 76 inches from center and 5 inches from edge.	S2; 3-inch sound knot 32 inches from center and 5 inches from top.	S2; 2-inch sound knot 30 inches from center near edge.	Horizontal shear.
39	S2; 2-inch sound knot 72 inches from center and 1 inch from edge.	S1; clear	S1; clear except for 1-inch sound knot 70 inches from center and 2 inches from edge.	S1; 1-inch sound knot 19 inches from center and 5 inches from top edge.	Brash and simple tension.
40	S4; 3-inch sound knot 25 inches from center and 3 inches from edge.	S2; 1½-inch sound knot 40 inches from center and 4 inches from edge.	S1; 2-inch rotten knot 80 inches from center, 8 inches from bottom.	S2; 2½-inch sound knot 25 inches from center, 3 inches from top.	Horizontal shear, simple tension.

In one other important respect the grading used differed from the rules of Department Circular 295. Rotten knots are not permitted in the S1, S2, and S3 grades of that circular (*15*), but in the grading shown in Tables 15 to 18 the rotten knots were considered as if they had been sound. Each timber containing one or more rotten knots is designated in the Tables 11 to 18 by means of a footnote reference.

Knots showing a slight amount of decay are prevalent in a number of species, such as western hemlock, and it is in the interest of utilization to permit them whenever it is feasible to do so. A practical way to grade timbers with rotten knots is to consider them the same as sound knots when the depth of the decay is less than half the diameter of the knot. It should be kept in mind, however, that the presence of rotten knots, even though they have no immediate effect on strength is, in general, undesirable in high-grade structural timbers.

It has been established from structural-timber tests that a given-sized knot causes only about half the reduction in bending strength when on the upper or compression side of a beam as when on the lower or tension face. Hence, in testing a beam different results could be obtained, depending on whether the most knots are turned up or down, assuming, of course, that the knot is the controlling defect. In this connection it has been the standard Forest Service procedure in testing to turn the timbers with the poorer side up, thus resulting in higher loads than would obtain if the timbers were reversed. The principal object of this procedure is to obtain information as to the effect of knots in compression as well as in tension. In service, of course, a beam is apt to be used either way, there being no assurance that the timber will be used most advantageously. For this reason the structural rules of Department Circular 295 and American lumber standards do not distinguish between the tension and compression faces of a beam. This practice is, of course, less efficient than grading a timber in accordance with its most advantageous placement in service, but is on the side of safety and, further, has simplicity to commend it.

GLOSSARY OF TERMS USED

Air dry.—(See p. 35.) Air-dry condition is the normal condition, with respect to moisture, of wood exposed to the air, although this condition may have been obtained by artificial means. The term "air dried" means dried by exposure to the air, while "kiln dried" indicates artificial drying. Air dry is a very general term and may mean any degree of dryness from about 6 per cent moisture, which may be obtained in very dry climates, to over 30 per cent moisture, as in timber dried to reduce its shipping weight. The degree of dryness, which will be attained in timber depends upon species, size, and the conditions under which the material is dried, especially such as humidity, method of piling, shelter, and time of drying. Twelve by twelve inch Douglas fir timbers, when air seasoned in the Lake States, will fall to about 18 per cent moisture in two years if properly spaced to allow circulation. One-inch lumber of the same species, under the same conditions, will dry to 15 per cent moisture in considerably less time, and small-sized timber dried in very dry regions will in some cases reach 6 per cent moisture. The same species, in the same sizes, piled in the same manner under shelter out of doors, will not fall much below 12 per cent moisture in the North Central and Great Lake States. In the coastal region of southeastern Alaska, where the humidity is relatively high, the moisture content of thoroughly air-seasoned lumber would probably be higher.

Dense.—Dense, as applied to wood, means compact, heavy (when dry), containing much wood substance in small space. For example, hickory is a very dense wood. The specific gravity of the wood when oven dry is a measure of the density. This figure is based on the weight, exclusive of moisture, but including any substances, such as rosin not volatile at 100° C., the temperature at which the moisture specimens are dried.

Elastic limit.—(See pp. 36 and 38.) The elastic limit (sometimes called proportional limit) is that point where the distortion ceases to be in proportion to the load. For example, if a beam deflects one-sixteenth of an inch with a 50-pound load it will deflect one-eighth of an inch with 100 pounds, and so on, each additional load of 50 pounds causing an additional deflection of one-sixteenth of an inch until the "elastic limit" is reached, after which the deflections increase more rapidly than the increase in load. A timber stressed beyond the elastic limit will not resume its original form upon the removal of the load.

Elasticity.—Elasticity is the property (possessed by most materials) of changing form with the application of force and recovering at once upon

release from the force. In any elastic material the amount of compression or deformation is proportional to the force applied, within the elastic limit. Air and other gases under compression are elastic. The most commonly recognized elastic material is rubber. Timber is elastic within comparatively narrow limits. The term "very elastic" as applied to wood is indefinite, because it may mean that the force required to produce a given deformation is great, and the recovery sudden as in an ivory ball (see "Modulus of elasticity"); or that the amount of distortion to the elastic limit is great as in a rubber ball, or that the wood possesses high elastic resilience, a combination of the two properties.

Fiber-saturation point.—(See definition p. 35.)

Fiber stress at elastic limit.—(See pp. 36, 38, and 73.)

Green.—Green is the condition of timber as taken from the living tree. Immediately upon being sawed from the tree lumber begins to lose moisture and otherwise change its condition. The rapidity of these changes is determined by the species, humidity, heat, and circulation of air.

Mechanical properties.—Mechanical properties are the properties of wood that enable it to resist deformations, loads, shocks, or forces. Thus the ability to resist shearing forces is a mechanical property of timber. (See "Strength" p. 74.)

Modulus of elasticity.—(See p. 37.) Modulus of elasticity is the ratio of stress per unit area to corresponding strain per unit length, the distortion or strain being within the elastic limit. Numerically, the modulus of elasticity of a material is the force in pounds required to stretch a sample of that material with a cross-sectional area of 1 square inch to double its length, on the assumption that the fibers would not be stressed beyond their elastic limit. Rubber has a very low modulus of elasticity, while that of steel is very high. It is, then, the measure of the stiffness or rigidity of a substance.

Modulus of rupture.—(See definition p. 36.)

Radial.—Radial means extending outward from a center or an axis. Thus a radial plane in a tree is one extending from the pith of the tree outward. The wide faces of a quarter-sawed board are radial surfaces.

Rings.—(See p. 34.) In timber grown in climates other than tropical well-defined concentric layers of wood can be seen on the cross section. These layers correspond closely to yearly increments of growth and for that reason are called annual rings. Each annual ring consists of a layer of spring wood and summer wood. It is difficult to distinguish spring wood and summer wood in some species.

Shear.—(See p. 39.) Shear is the name of the stress which tends to keep two adjoining planes or surfaces of a body from sliding, one on the other, under the influence of two equal and parallel forces acting in opposite directions. A force which produces shear (or shearing stress) in a material is called a shearing force.

Spring wood.—The lighter and more porous layer of wood in the annual rings of a tree is known as the spring wood, or early wood. As the name implies, it is produced in the spring growth, or in the earlier part of the growing season.

Strain.—The deformation or distortion produced by a stress or force is known as strain.

Strength.—The term "strength" as ordinarily used is a very indefinite one. It is usually thought of in connection with external loads or forces. Strength in its broad sense is a measure of the mechanical properties, or of the ability of a timber to resist stress or deformation. Thus, strength in shear, bending strength, compressive strength, hardness, stiffness, toughness. These last three properties are not always thought of in connection with the term strength, but are unconsciously included whenever they are important in a specific use. Seldom, if ever, do any two species contain all the various properties in the same degree. This accounts for the special uses of the different species. Much confusion often arises from comparing species for a special use on the basis of properties or strength values not of first importance in the specific instance.

Stress.—Stress is distributed force. Fiber stress is the distributed force tending to compress, tear apart, or change the relative position of the wood fibers. Stress is measured by the force per unit area. Thus a short column 2 inches square (4 square inches) and supporting a load of 2,000 pounds will be under a stress or fiber stress of 500 pounds per square inch.

Summer wood.—(See p. 34.) Summer wood is that denser layer of wood in the annual rings of a tree which is put on in summer or the latter part of the growing season.

Tangential.—Tangential, as applied in this bulletin, means tangent to or parallel to the curves of the annual rings in a cross section. Thus, a tangential surface is a surface perpendicular to the radius of a tree. A board in which the wide face is a tangential surface is also called flat sawn.

WORKING STRESSES

The figures in Tables 2, 3, and 4 are most directly applicable to the comparison of species for uses requiring wood free from defects. For structural material of grades in which the size, location, and number of defects are limited with reference to their effect on strength, the relative strengths of the species are better represented by allowable working stresses used in design. Working stresses for Select and Common structural grades conforming to the basic provisions of American Lumber Standards are given in Table 19. They are technical in nature and have been arrived at from a consideration of the strength and variability of the clear wood, the relation of density to strength, the effect of defects in structural sizes, the effect of long-continued loading, and the inherent characteristics of the species, such as prevalence of knot clusters, tendency to check in seasoning, and prevalence of shakes. The figures in Tables 2, 3, and 4 are the average results of tests on clear wood of the different species; those of Table 19 are assigned values, based not only on tests, but on experience and judgment.

TABLE 19.—*Working stresses, in pounds per square inch, for timber conforming to the basic provisions for select and common structural material of American lumber standards* [1]

[As recommended by the Forest Products Laboratory, Forest Service, United States Department of Agriculture]

Species	Fiber stress in bending [2]										Compression perpendicular to grain			Horizontal shear [3]		Compression parallel to grain (short columns having ratio of length to least dimension of 11 or less)						Average modulus of elasticity [4]
	Continuously dry		Occasionally wet but quickly dried				More or less continuously damp or wet				Continuously dry	Occasionally wet but quickly dried	More or less continuously damp or wet	Not varied with conditions of exposure		Continuously dry		Occasionally wet but quickly dried		More or less continuously damp or wet		Not varied with conditions of exposure or with grade
	All thicknesses		Material 4 inches and thinner		Material 5 inches and thicker		Material 4 inches and thinner		Material 5 inches and thicker		Select and common grades			Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	
	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade												
Ash, black	1,000	800	800	680	900	720	710	600	800	640	300	200	150	90	72	650	520	550	440	500	400	1,100,000
Ash, commercial white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800	500	375	300	125	100	1,100	880	1,000	800	900	720	1,500,000
Aspen and large-tooth aspen	800	640	580	490	650	520	440	370	500	400	150	125	100	80	64	700	560	550	440	450	360	900,000
Basswood	800	640	580	490	650	520	440	370	500	400	150	125	100	80	64	700	560	550	440	450	360	900,000
Beech	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Birch, paper	900	720	670	570	750	600	530	450	600	480	200	150	100	80	64	650	520	550	440	450	360	1,000,000
Birch, yellow and sweet	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Cedar, Alaska	1,100	880	890	760	1,000	800	800	680	900	720	250	200	150	90	72	800	640	750	600	650	520	1,200,000
Cedar, western red	900	720	710	600	800	640	670	570	750	600	200	150	125	80	64	700	560	700	560	650	520	1,000,000
Cedar, northern and southern white	750	600	580	490	650	520	530	450	600	480	175	140	100	70	56	550	440	500	400	450	360	800,000
Cedar, Port Orford	1,100	880	890	760	1,000	800	800	680	900	720	250	200	150	90	72	900	720	825	660	750	600	1,200,000
Chestnut	950	760	760	650	850	680	620	530	700	560	300	200	150	90	72	800	640	700	560	600	480	1,000,000
Cottonwood, eastern and black	800	640	580	490	650	520	530	450	600	480	150	125	100	80	64	700	560	550	440	450	360	900,000
Cypress, southern	1,300	1,040	980	830	1,100	880	800	680	900	720	350	250	225	100	80	1,100	880	1,000	800	800	640	1,200,000
Douglas fir (western Washington and Oregon type) [5]	1,600	1,200	1,233	983	1,387	1,040	948	756	1,067	800	[6] 347	[6] 240	[6] 213	90	72	1,173	880	1,067	800	907	680	1,600,000

Douglas fir (dense) [5]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933	379	262	233	105	84	1,283	1,027	1,167	933	992	793	1,600,000
Douglas fir (Rocky Mountain type)	1,100	880	800	680	900	720	620	530	700	560	275	225	200	85	68	800	640	800	640	700	560	1,200,000
Elm, rock	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,300,000
Elm, slippery and American	1,100	880	800	680	900	720	710	600	800	640	250	175	125	100	80	800	640	750	600	650	520	1,200,000
Fir, balsam	900	720	670	570	750	600	530	450	600	480	150	125	100	70	56	700	560	600	480	500	400	1,000,000
Fir, commercial white	1,100	880	800	680	900	720	710	600	800	640	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Gum, red, black, and tupelo	1,100	880	800	680	900	720	710	600	800	640	300	200	150	100	80	800	640	750	600	650	520	1,200,000
Hemlock, eastern	1,100	880	800	680	900	720	710	600	800	640	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Hemlock, western	1,300	1,040	980	830	1,100	880	800	680	900	720	300	225	200	75	60	900	720	900	720	800	640	1,400,000
Hickory (true and pecan)	1,900	1,520	1,330	1,130	1,500	1,200	1,070	910	1,200	960	600	400	350	140	112	1,500	1,200	1,200	960	1,000	800	1,800,000
Larch, western	1,200	960	980	830	1,100	880	800	680	900	720	325	225	200	100	80	1,100	880	1,000	800	800	640	1,300,000
Maple, sugar and black	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Maple, red and silver	1,000	800	800	680	900	720	620	530	700	560	350	250	200	100	80	800	640	700	560	600	480	1,100,000
Oak, commercial red and white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800	500	375	300	125	100	1,000	800	900	720	800	640	1,500,000
Pine, southern yellow [5]	------	1,200	------	983	------	1,040	------	756	------	800	(6)	(6)	(6)	------	88	------	880	------	800	------	680	1,600,000
Pine, southern yellow (dense) [5]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933	379	262	233	128	103	1,283	1,027	1,167	933	992	793	1,600,000
Pine, northern white, western white, western yellow, and sugar	900	720	710	600	800	640	670	570	750	600	250	150	125	85	68	750	600	750	600	650	520	1,000,000
Pine, Norway	1,100	880	890	760	1,000	800	710	600	800	640	300	175	150	85	68	800	640	800	640	700	560	1,200,000
Poplar, yellow	1,000	800	800	680	900	720	710	600	800	640	250	150	125	80	64	800	640	700	560	600	480	1,100,000
Redwood	1,200	960	890	760	1,000	800	710	600	800	640	250	150	125	70	56	1,000	800	900	720	750	600	1,200,000
Spruce, red, white, and Sitka	1,100	880	800	680	900	720	710	600	800	640	250	150	125	85	68	800	640	750	600	650	520	1,200,000
Spruce, Engelmann	750	600	580	490	650	520	440	370	500	400	175	140	100	70	56	600	480	550	440	450	360	800,000
Sycamore	1,100	880	800	680	900	720	710	600	800	640	300	200	150	80	64	800	640	750	600	650	520	1,200,000
Tamarack (eastern)	1,200	960	980	830	1,100	880	800	680	900	720	300	225	200	95	76	1,000	800	900	720	800	640	1,300,000

[1] American lumber standards: Basic provisions for American lumber standards grades are published by the U. S. Department of Commerce in Simplified Practice Recommendation No. 16 (*22*); specifications for grades conforming to American lumber standards are published in the 1927 Standards of the American Society for Testing Materials, and in Amer. Ry. Engr. Assoc. Bul.

[2] Stress in tension: The working stresses recommended for fiber stress in bending may be safely used for tension parallel to grain.

[3] Joint details: The shearing stresses for joint details may be taken for any grades as 50 per cent greater than the horizontal shear values for the Select grade.

[4] Factors to be applied to average modulus of elasticity values: The values for modulus of elasticity are average for species and not safe working stresses. They may be used as given for computing average deflection of beams. When it is desired to prevent sag in beams values one-half those given should be used. In figuring safe loads for long columns values one-third those given should be used.

[5] Exact figures given: In order to preserve the exact numerical relations among working stresses for grades involving rate of growth and density requirements the values for Douglas fir (western Washington and Oregon type) and for southern yellow pine have not been rounded off, as have the values for the other species.

[6] Working stresses for the Common grade: The values given are for the Select grade. Working stresses in compression perpendicular to grain for the common grades of Douglas fir (western Washington and Oregon type) and southern yellow pine are 325, 225, and 200, respectively, for continuously dry, occasionally wet but quickly dried, and more or less continuously damp or wet conditions.

LITERATURE CITED

(1) AMERICAN RAILWAY ENGINEERING ASSOCIATION.
1929. SPECIFICATIONS FOR STRUCTURAL WOOD JOIST, PLANK, BEAMS, STRINGERS AND POSTS. Amer. Ry. Engin. Assoc. Bul. 314: 1178–1224.

(2) AMERICAN SOCIETY FOR TESTING MATERIALS.
1927. STANDARD METHODS FOR TESTING SMALL CLEAR SPECIMENS OF TIMBERS. SERIAL DESIGNATION D143–27. A. S. T. M. Standards . . . 1927, Pt. II, Non-metallic materials, p. 627–663, illus.

(3) ———
1927. STANDARD SPECIFICATIONS FOR STRUCTURAL WOOD JOIST, PLANKS, BEAMS, STRINGERS, AND POSTS. SERIAL DESIGNATION D245–27. A. S. T. M. Standards . . . 1927, Pt. II, Non-metallic materials, p. 581–622, illus.

(4) ———
1927. STANDARD METHODS FOR CONDUCTING STATIC TESTS OF TIMBER IN STRUCTURAL SIZES. SERIAL DESIGNATION D198–27. A. S. T. M. Standards . . .1927, Pt. II, Non-metallic materials, p. 664–682, illus.

(5) BETTS, N. DE W.
1914. ROCKY MOUNTAIN MINE TIMBERS. U. S. Dept. Agr. Bul. 77, 34 p., illus.

(6) CLINE, M., and HEIM, A. L.
1912. TESTS OF STRUCTURAL TIMBERS. U. S. Dept. Agr., Forest Serv. Bul. 108, 123 p., illus.

(7) DRAKE, G. L.
1923. BIRCH-SPRUCE FORESTS OF SOUTHWESTERN ALASKA. Timberman 25 (2): 51–53, illus.

(8) GUTHRIE, J. D.
1922. ALASKA'S INTERIOR FORESTS. Amer. Forestry 28 (344): 451–455, illus.

(9) HEINTZLEMAN, B. F.
1923. THE STANDING TIMBER RESOURCES OF ALASKA. West Coast Lumberman 44 (518): 102–103, 108, illus.

(10) ———
1928. PULP-TIMBER RESOURCES OF SOUTHEASTERN ALASKA. U. S. Dept. Agr. Misc. Pub. 41, 35 p., illus.

(11) HORNOR, R. R., and TUFFT, H. E.
1925. MINE TIMBER: ITS SELECTION, STORAGE, TREATMENT, AND USE. (With a chapter on methods of prolonging life of mine timber by G. M. Hunt.) U. S. Dept. Interior, Bur. Mines Bul. 235, 118 p., illus.

(12) JOHNSON, R. P. A., and GIBBONS, W. H.
1929. PROPERTIES OF WESTERN HEMLOCK AND THEIR RELATION TO THE USES OF THE WOOD. U. S. Dept. Agr. Tech. Bul. 139, 62 p., illus.

(13) MARKWARDT, L. J.
1930. COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U. S. Dept. Agr. Tech. Bul. 158, 39 p., illus.

(14) NEWLIN, J. A., and GAHAGAN, J. M.
1930. TESTS ON LARGE TIMBER COLUMNS AND PRESENTATION OF THE FOREST PRODUCTS LABORATORY COLUMN FORMULA. U. S. Dept. Agr. Tech. Bul. 167, 44 p., illus.

(15) ——— and JOHNSON, R. P. A.
1923. BASIC GRADING RULES AND WORKING STRESSES FOR STRUCTURAL TIMBERS. U. S. Dept. Agr. Circ. 295, 23 p., illus.

(16) ——— and JOHNSON, R. P. A.
1924. STRUCTURAL TIMBERS; DEFECTS AND THEIR INFLUENCE ON STRENGTH. A. S. T. M. Proc. . . . 1924, Pt. II, Tech. Papers, p. 975–990, illus.

(17) ——— and WILSON, T. R. C.
1917. MECHANICAL PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U. S. Dept. Agr. Bul. 556, 47 p., illus.

(18) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES, THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 295 p.
(19) ———
1908. FOREST TREES OF THE PACIFIC SLOPE. U. S. Dept. Agr., Forest Serv. 441 p., illus.
(20) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE.
1927. AMERICAN FORESTS AND FOREST PRODUCTS. U. S. Dept. Agr. Statis. Bul. 21, 324 p.
(21) UNITED STATES DEPARTMENT OF COMMERCE, BUREAU OF CENSUS.
1930. FOREST PRODUCTS: 1928, LUMBER, LATH, AND SHINGLES. 23 p.
(22) UNITED STATES DEPARTMENT OF COMMERCE, BUREAU OF STANDARDS.
1929. LUMBER. U. S. Dept. Com., Bur. Standards Rev. Simplified Pract. Recommendation R16–29, Ed. 4, 94 p., illus.
(23) UNITED STATES DEPARTMENT OF THE INTERIOR.
1930. ANNUAL REPORT OF THE GOVERNOR OF ALASKA TO THE SECRETARY OF THE INTERIOR FOR FISCAL YEAR ENDING JUNE 30, 1930. APPENDIX H. REPORT OF COLLECTOR OF CUSTOMS. 131 to 139.
(24) ZON, R., and SPARHAWK, W. N.
1923. FOREST RESOURCES OF THE WORLD. 2 v., illus. New York.

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DEVELOPMENTAL STAGES OF SOME NEMATODES OF THE SPIRUROIDEA PARASITIC IN POULTRY AND GAME BIRDS

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page
Review of preceding investigations	1
Methods used in the present investigation	2
Tetrameres americana Cram, 1927	3
Development in intermediate host	3
Development in final host	4
Rate of development	5
Cheilospirura hamulosa (Diesing, 1851) Diesing, 1861	8
Development in intermediate host	8
Development in final host	9
Description of adult parasite	12
Cheilospirura spinosa Cram, 1927	13
Development in intermediate host	14
Development in final host	15
Dispharynx spiralis (Molin, 1858) Skrjabin, 1916	18
Development in intermediate host	19
Development in final host	20
Seurocyrnea colini (Cram, 1927) Cram, 1930	21
Development in intermediate host	22
Development in final host	23
Summary	24
Literature cited	26

REVIEW OF PRECEDING INVESTIGATIONS

Previous investigations conducted in various parts of the world have revealed the life histories of a few of the nematodes belonging to the Spiruroidea which occur in domestic birds. A discussion of these and more recent findings has been included in a paper by the writer.[2] The findings of earlier investigators may be very briefly summarized as follows:

By comparative studies of a morphological nature three crustaceans were shown to be the intermediate hosts of three nematodes,

[1] J. R. Christie, of the Bureau of Plant Industry, and C. H. Popenoe and F. L. Campbell, of the Bureau of Entomology, have assisted the writer most generously by supplying laboratory-reared grasshoppers for the experiments here described. E. A. Chapin, of the Bureau of Entomology, and J. O. Maloney, of the Smithsonian Institution, identified the dung beetles and the isopods, respectively. The Animal Husbandry Division of the Bureau of Animal Industry supplied day-old, incubator-hatched chickens. The investigation of parasites of ruffed grouse was undertaken in cooperation with the New England Ruffed Grouse Investigation Committee; the writer is especially indebted to A. O. Gross of that committee for obtaining the live grouse for the feeding experiments, and for collecting and submitting unpreserved specimens of *Dispharynx spiralis* and *Cheilospirura spinosa* from grouse. The study of parasites of bobwhite quail was undertaken in cooperation with the Bureau of Biological Survey, and the writer is especially indebted to H. L. Stoddard, of that bureau, for aid in obtaining material. W. B. Coleman, of the White Oak quail farm, Richmond, Va., has also been most generous in his cooperation. The Connecticut Game Commission made possible the successful completion of the life-history experiments on *Seurocyrnea colini* by furnishing quail, originating in Mississippi, which were infected with that parasite.

[2] Paper presented at The Fourth World's Poultry Congress, London, July, 1930.

namely, the isopod, *Porcellio laevis*, serving for *Dispharynx spiralis* as occurring in the chicken; the amphipod, *Gammarus pulex*, and the cladoceran, *Daphnia pulex*, for *Tetrameres fissispina*, as occurring in ducks; and the cladoceran, *Daphnia pulex*, also for *Echinuria uncinata*, as occurring in ducks. By experimental demonstrations two insects were added by the earlier investigators to the list of intermediate hosts for three other nematodes, namely, one of the Isoptera, the termite *Macrohodotermes mossambicus transvaalensis* (synonym: *Hodotermes pretoriensis*), serving for *Hartertia gallinarum* of chickens, and one of the Orthoptera, the roach, *Pycnoscelus surinamensis*, for *Oxyspirura parvovum* and *O. mansoni*, also of chickens.

Investigations carried on by the writer have recently added to this list the names of seven arthropod intermediate hosts, of which five are insects and two are crustaceans, serving for six spirurids. These are as follows: Two members of the Coleoptera, the dung beetle, *Phanaeus vindex* (synonym: *P. carnifex*) and *Copris minutus*, serving for a species of Gongylonema, tentatively identified as *G. ingluvicola* of the chicken; three members of the Orthoptera, the grasshoppers, *Melanoplus femurrubrum* and *M. differentialis*, both serving for *Tetrameres americana* and *Cheilospirura hamulosa* of chickens and for *C. spinosa* of gallinaceous game birds, and the cockroach, *Blattella germanica*, serving for *Seurocyrnea colini* of game birds; and two isopods, the sow bugs, *Porcellio scaber* and *Armadillidium vulgare*, serving for *Dispharynx spiralis* of gallinaceous game birds.

In the case of the species of Gongylonema, a natural infection in the dung beetles was discovered incidental to the conducting of experiments on another spirurid, *Physocephalus sexalatus* of swine, for which those beetles also serve as intermediate hosts; in a chicken a single male specimen and in a rabbit two female specimens of Gongylonema were developed, which were tentatively identified as *G. ingluvicola*, pending further investigation when additional material is available. However, in the case of the other five spirurids, all stages of the life cycle were experimentally produced, and it is planned here to describe the various stages observed in the development of each of these nematodes.

METHODS USED IN THE PRESENT INVESTIGATION

The grasshoppers used as intermediate hosts in the present study were laboratory reared, but all the other arthropods were collected in the wild. The embryonated eggs of the nematodes were obtained from the uteri of the worms and in some cases from the contents of the digestive tract of the infected birds and were fed to the arthropods with green stuff or with finely ground cereals.

The bird hosts used for the life-history experiments were confined indoors throughout the entire period of the experiment. The chickens were hatched in incubators and in all but a few cases were kept on raised wire-mesh floors through which the droppings passed, first in electrically heated brooders and later in cages, but in both instances under an insect-proof cover made of fine wire screening of approximately 2-millimeter mesh. Control chickens were kept in the same compartment as those experimentally fed.

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Tetrameres americana: A, Adult male; B, female. Original

This method has proved to be highly reliable, control chickens being consistently negative as regards the presence of parasites and the chickens which had been artificially infected showing no parasites other than those fed to them. This method was followed in all instances until the life history was definitely established; in a few cases, as in the case of the infections with *Tetrameres americana* and with *Cheilospirura hamulosa*, in order that observations of a more general clinical nature might be made, chickens were released later in indoor pens. The floors of these pens were of concrete, and the windows were screened; the pens were in a new building and had never been used for chickens other than those experimentally infected.

Pigeons were held in cages of the kind described, but the birds other than pigeons and chickens were held in the indoor pens rather than in cages. The quail had been hatched in incubators and reared artificially; the ducks and turkeys were obtained from commercial poultry raisers and the ruffed grouse from a Canadian dealer. Therefore the previous histories in these cases were unknown.

TETRAMERES AMERICANA CRAM, 1927 (*5*)[3]

Synonym: *Tropisurus americanus* (Cram, 1927) Baylis, 1929 (*2*)

Members of the genus Tetrameres and related genera are unique among nematodes in birds in that the females do not conform to the usual shape of roundworms, that is, elongated and cylindrical, but, after entering the glands of the stomach, become globular in shape as the body becomes distended with eggs; there are two small projections, one of which, the head, is at one side, and the other, the tail, on the opposite side. The worm lies in the gland in such a position that the tail protrudes into the duct of the gland, to facilitate the passage of the eggs, and the head is in the fundus of the gland, to facilitate feeding. The female becomes blood red in color (pl. 1), another unusual characteristic. The males, on the other hand, retain throughout life the elongated, slender form of body and are practically without color. This sexual dimorphism in species of Tetrameres, correlated with the life habit, has been compared with that of the chigoe flea, which occurs in tropical America and Africa, the female burrowing into the skin of man and of various domestic and wild animals, becoming engorged with blood, and its body swelling to a globular form as it is distended with eggs.

T. americana is of fairly common occurrence in chickens (*Gallus gallus*) in North America, and in some localities is of considerable pathological significance. It occurs also in bobwhite quail (*Colinus virginianus*).

DEVELOPMENT IN INTERMEDIATE HOST

Embryonated eggs of *T. americana*, when fed to the grasshoppers, *Melanoplus femurrubrum* and *M. differentialis*, hatch in the digestive tract, and the larvae pass into the body cavity, where they can be found in an active, unencysted state for the first 10 days after the feeding. They then penetrate the tissues, chiefly the muscles, and

[3] Italic numbers in parentheses refer to Literature Cited, p. 26.

become loosely encysted; in heavy infestations all parts of the body, including the head and the femurs, contain the larvae. On dissection of the grasshoppers in a shallow layer of water, the larvae excyst quickly and become very active. In 42 days, possibly sooner, the larvae are infective for the final host. The vitality of the grasshoppers appeared to be considerably reduced by the infection; a certain number died, and those which survived were droopy and inactive, a condition which would make them easy prey for food-seeking fowls in nature.

FIGURE 1.—*Tetrameres americana*. Tail of third-stage larva

The most striking characteristics of the third-stage infective larva are as follows: Head end blunt, without lips or other noticeable structures. Cuticle with distinct cross striations. Total length of body, 1.8 to 1.9 mm.; first part of esophagus (muscular portion), 216 to 225μ long; second part of esophagus (glandular portion), 540 to 550μ long; the ratio of total length of esophagus to total body length is therefore as 1 to about 2.4. Anal aperture 170 to 184μ from tail end. Rectum refractive to light, as if chitinized. Tail (fig. 1) with a circle of 12 papillae at its posterior end, the 4 papillae situated in the lateral, ventral, and dorsal fields being larger and more curved than the other 8, of which there are 2 in each of the 4 submedian fields. A pair of slender, sharply pointed papillae are situated in the lateroventral field at a distance of 88μ and 100μ, respectively, from the tail end.

DEVELOPMENT IN FINAL HOST

In the experiments conducted by the writer, the third-stage larvae of *T. americana* obtained from experimentally infected grasshoppers have proved infective for young and adult chickens, for the domestic duck (*Anas platyrhyncha domestica*), for bobwhite quail, and for ruffed grouse (*Bonasa umbellus*), in the cases shown in Table 1.

TABLE 1.—*Development of Tetrameres americana in various bird hosts*

Host	Birds infected after feeding	Nematodes developed per bird	Birds not infected after feeding	Controls (all negative)
	Number	*Number*	*Number*	*Number*
Young chicken	48	1 to 240	9	120
Adult hen	1	16	0	3
Pigeon	1	15	2	4
Young duckling	1	1	0	1
Adult duck	0	0	0	0
Bobwhite quail	2	3 and 6	0	10
Ruffed grouse	1	23	0	5

As regards the negative results in chickens, in seven of the nine negative cases the chickens were not killed and examined until from five to eight months had elapsed after the feeding of the infected-grasshopper parts; the possibility suggests itself, therefore, that the chickens in at least some of these cases may have been lightly infected and that the life of the parasites was not five to eight months long in those cases. This supposition is borne out by the finding

of a disintegrated female specimen of Tetrameres in the wall of the proventriculus of one of the chickens, killed eight months after the experimental feeding; the red color had disappeared, and the cuticle was partially disintegrated, but the mass of coiled uteri and the black saclike intestine remained.

The difficulty in producing experimental infections of ducks—only one specimen of parasite, a female, developing in the case of the young duck and no parasites developing in the adult duck—suggests that ducks are not normal hosts of *T. americana.* This observation is substantiated by the fact that natural infestations of domestic ducks with this parasite have never been discovered in this country, so far as the writer knows. This is contrary to the situation in Europe, where the reports of the European species, *T. fissispina*, are as frequent from ducks as from chickens, if not more so. The difference in the intermediate hosts of the two species may be correlated with this difference in final hosts, the species found usually in ducks and other water birds having as intermediate hosts aquatic crustaceans, as noted in the introduction to this bulletin, and the species found normally in chickens having as intermediate hosts terrestrial insects, grasshoppers. Gallinaceous birds would ingest crustaceans accidentally in their drinking water with much greater frequency than water birds would ingest terrestrial

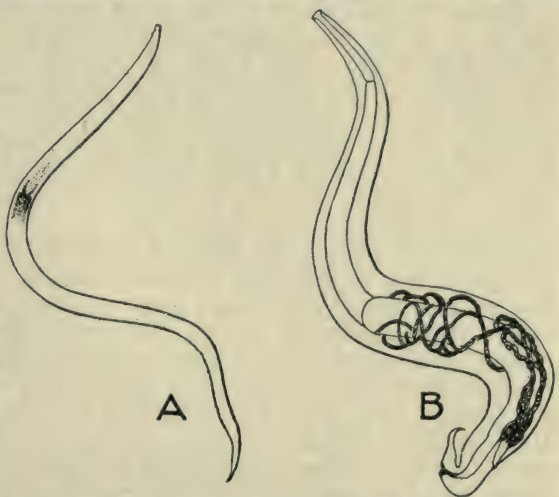

FIGURE 2.—Immature forms of *Tetrameres americana*: (A) Male and (B) female, at the end of 14 days in the chicken. About thirty times natural size

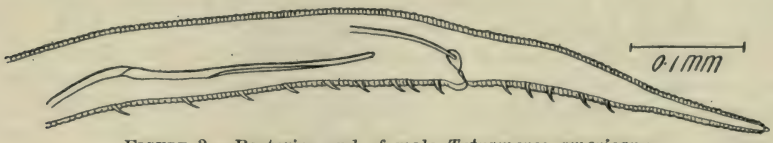

FIGURE 3.—Posterior end of male *Tetrameres americana*

insects, such as grasshoppers; the wider range of bird hosts for *T. fissispina* is, therefore, easily understood.

Natural infestations of bobwhite quail with *T. americana* have been noted, but the present report of experimental infestations in the ruffed grouse and pigeon appears to be the first observation of this parasite in these hosts.

RATE OF DEVELOPMENT

As regards the rate of development, the following observations have been made: Eleven days after being fed to a chick the larvae were

recovered from the surface of the mucosa of the proventriculus as fourth-stage larvae which were about to shed their cuticles for the last time, or as immature adults with as yet no noticeable sexual differentiation. After 14 days the immature females (fig. 2, *B*) were in the glands of the stomach and displayed primary and secondary sexual characteristics, the most noticeable being expansion of the body and the presence of ovarian and uterine coils confined to the intestinal region; these developments were accompanied by the appearance of the four longitudinal, cuticular bands which later constricted the body. The males (fig. 2, *A*) were at this time still on the surface of the mucosa and as yet showed no adult characters. After 16 days no nematodes were found on the surface, even by gentle scraping of the mucosa, but some were expelled upon squeezing of the glands, the males often appearing simultaneously with the females; the males then showed their adult characters, namely, fully developed spicules and spines (fig. 3), the latter along the entire length of the body. At the end of 19 days and also at the end of 25 days a few males were collected from the surface of the mucosa, but most of them were more deeply embedded. The males had attained their maximum size at that time. The female body had expanded considerably, but its total length had decreased with the expansion in width; the intestine had become saclike, and the coils of the ovaries and uteri had increased but as yet contained no eggs. Both males and females showed evidence at that stage of having fed on blood, the heads of the worms and the contents of their digestive tracts being stained with blood. Small, petechial hemorrhages were to be seen in the glands where worms were situated, and the wall had become greatly thickened and congested.

There is evidence that this period of invasion of the stomach wall is the period that most seriously affects the health of the chicks, as it was then that the largest number of deaths occurred, and in nonfatal cases that the most severe clinical symptoms, emaciation and droopiness, were noted. That the diet may play an important part in the chicks' resistance at this stage is indicated by the fact that of a group of four infected chicks which were being fed a vitamin-deficient diet, that is, one in which no yeast or cod-liver oil was present, all four died, on the eleventh, thirteenth, fourteenth, and twenty-fifth day, respectively, whereas of a comparable group of four infected chicks on a vitamin-sufficient diet, none died. Control chicks on the vitamin-deficient diet survived the period of experimentation, so that the conclusion is justified that the severity of the parasitic infestation was correlated with the vitamin content of the diet. More extensive experimentation along this line is highly desirable, being of considerable practical importance.

By the twenty-ninth day practically all the males had returned to the surface, only an occasional one being found in the glands. At this period the females for the first time showed the bright-red color of the body; the saclike intestine was seen within the body, appearing very black in color, since the uterine coils were not yet sufficiently opaque to obscure it.

At the end of 35 days the females were gravid, but the eggs were not yet embryonated; after 45 days the eggs were embryonated, and development was complete, except that the maximum size had not

yet been attained. At 2 months the size was approximately the same as at 45 days, but at 3 months it had increased to the maximum.

These observations as to the location of the male specimens of *T. americana* differ from the descriptions of the behavior of *T. fissispina* in this respect: In the latter species the mating of male and female is said to occur on the surface of the mucosa, the females then entering the canals of the glands of Lieberkuehn and the males remaining in the lumen of the stomach. In the American species, on the other hand, it is evident that the female sex characters appear at an earlier date than those of the male. The female enters the gland before the male becomes adult. The male follows later and, after the period of mating has passed, again returns to the surface of the mucosa.

Table 2 summarizes the rate of development of *T. americana*, as shown in the measurements made at different stages in its development.

TABLE 2.—*Measurements of Tetrameres americana at various stages in its development*

Part measured	In grasshopper at 42 days—third stage	In chicken at—				
		11 days	14 days		19 days	
			♀	♂	♀	♂
Body length	1.8 to 1.9 mm.	2.6 mm.	3.0 mm.	2.8 mm.	3.0 mm.	3.8 mm.
Body width	56 to 64μ.	72μ.	320μ.	88μ.	546μ.	96μ.
Tail length	170 to 185μ.	288μ.	248μ.	256μ.	280μ.	256μ.
Vulva from tail end			456μ.		440μ.	
Spicules				None.		312μ and 112μ.
Eggs					Present, without shells.	

Part measured	In chicken at—				
	25 days		35 days	45 days	90 days
	♀	♂	♀	♀	♀
Body length	2.8 mm.	5.2 mm.	3.7 mm.	3.5 to 4.2 mm.	4 mm.
Body width	1.1 mm.	112μ.	1.6 mm.	2 mm.	3 mm.
Tail length	208μ.	288μ.	234μ.	256μ.	312μ.
Vulva from tail end	368μ.		546μ.	600μ.	620μ.
Spicules		312μ and 112μ.			
Eggs	With shells but not embryonated.		48 by 24μ; not embryonated.	48 to 56μ by 28 to 32μ; embryonated.	Same.

CHEILOSPIRURA HAMULOSA (DIESING, 1851) DIESING, 1861 (8)

Synonyms: *Spiroptera hamulosa* Diesing, 1851 (7); *Dispharagus hamulosus* (Diesing, 1851) Stossich, 1890 (18); *Spiroptera perforans* Centoscudi, 1911 (4); *Acuaria hamulosa* (Diesing, 1851) Railliet, 1911 (12)

Cheilospirura hamulosa is cosmopolitan in distribution, occurring most frequently in the chicken but being known also in the turkey. The nematode is found in the gizzard, associated with small, fleshy growths on the surface of the muscular wall, under the corneous lining, or in burrows in the wall. There is an opening leading to the inner surface of the gizzard for the passage of the eggs of the parasite; these openings are often circumscribed by a rough, brown-colored area on the inner surface of the corneous lining.

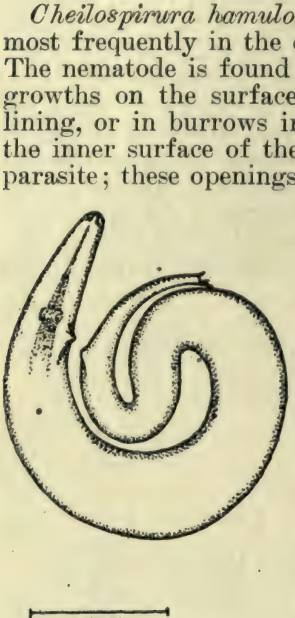

FIGURE 4.—*Cheilospirura hamulosa*. Third-stage larva from grasshopper

In the United States *C. hamulosa* is widespread in distribution and in some localities is the cause of numerous fatalities in infected flocks.

DEVELOPMENT IN INTERMEDIATE HOST

Attempts to produce infections in cockroaches, sow bugs, ground beetles, and crickets were unsuccessful; however, as the result of similar feeding experiments, two species of grasshoppers, *Melanoplus femurrubrum* and *M. differentialis*, were found to be capable of serving as intermediate hosts of *C. hamulosa*. The larvae which hatch from the eggs migrate into the body cavity of the grasshopper and develop among the tissues, chiefly in the muscles, to the third stage, which is infective for the bird host. At this stage the nematode is tightly coiled upon itself, and the tissues form a thin-walled cyst around it. The larvae uncoil very slowly when the tissues are dissected in a small quantity of water, and they seldom become more outstretched than the position shown in Figure 4. The coiled form and relative inactivity of these larvae make them strikingly different from the corresponding larvae of *Tetrameres americana*, when the two species of nematodes occur in the same grasshopper. As noted previously, the larvae of *T. americana* quickly uncoil and become very active in water.

The third-stage larva of *C. hamulosa* is 700μ in length by 44μ to 50μ wide. A striking characteristic of this larva, as also that of *C. spinosa* (p. 14) and, therefore, possibly a generic character, is the reversal of the curve of the body which is made by the tail. (Fig. 4.) The head end (fig. 5, A) is rounded but has two prominent lips and four conspicuous submedian papillae. There is no evidence of cordons such as are seen in the adult. The anus is 96μ from the end of the body. The tail end of this larval form of *C. hamulosa* bears four comparatively long digitate papillae (fig. 5, B); one, on the dorsal surface, is larger than the others. The two lateral papillae and the ventral papilla are approximately the same size. On the dorsal surface, at the base of the papillae, the cuticle projects slightly, as a collar. A comparison of these tail structures of the larva of *C. hamu-*

losa with those of *C. spinosa* (fig. 12, B) shows them to be similar in number and in general arrangement but slightly different in shape and considerably different in size; *C. hamulosa*, which is the smaller larva, has the larger caudal papillae.

DEVELOPMENT IN FINAL HOST

As a result of feeding third-stage larvae of *C. hamulosa* dissected from grasshoppers, the remaining stages of the life cycle of the nematode have been obtained experimentally in the final host. The larvae were found to be infective for chickens as early as 22 days and as late as 67 days after the ingestion of the nematode eggs by the grasshoppers. The results of the experiments were as follows:

Young chickens: Positive results, 16 cases; negative results, 15 cases; controls (all negative), 198. Negative results were also obtained when feedings were given to a chicken, a pigeon, a ruffed grouse, a bobwhite quail, and a turkey, all these birds being adult.

In the 16 cases in which chickens were infected experimentally with *C. hamulosa*, the nematodes were collected from the gizzards of the fowls at varying periods, ranging from 11 days to 9½ months; in 7 of the cases the nematodes were adult when collected, whereas in the other 9 cases immature specimens were obtained. Observations made in this way as to the rate and location of development include the following:

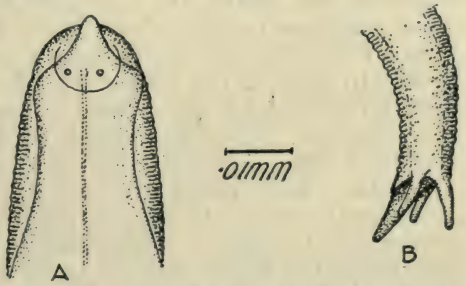

FIGURE 5.—*Cheilospirura hamulosa:* A, head end; B, tail end of third-stage larva

C. hamulosa larvae collected 11 days after the feeding of the chicken from the underside of the corneous lining of the gizzard, possessed the head and tail characters of third-stage larvae, but had attained a length of 1.2 millimeters and a width of 64μ. Sixteen days after the feeding of the chicken, however, larvae collected from this site showed characteristics of immature adults. Sexual differentiation was apparent in that the nematodes were of two sizes; the larger ones clearly showed the primordia of the vulva and ovejector. The cordons were conspicuous in the submedian fields of the cuticle, and the head structures resembled those of the adult. Measurements made of the nematodes at this time were as follows: Male, 2 millimeters long by 72μ wide; anus 200μ from tail end; cordons extending posteriorly from the head end for a distance of 340μ. Female, 2.5 millimeters long by 72μ wide; a primordium of vulva somewhat posterior to middle of body, dividing body length in ratio of 9 to 7; anus 190μ from tail end; cordons strongly developed for a distance of 288μ and discernible for an additional 360μ, from the head end. At the end of 19 days the males were 3 millimeters long, with cordons developed for a distance of 780μ from the head end; the females were 3.8 millimeters long, with cordons 1.2 millimeters long. Throughout this period of development the nematodes remained on the surface of the muscular wall of the gizzard, under the corneous lining; at the end of 25 days, however, they were found

to be penetrating the muscular wall, the head end being inserted. Males and females did not enter the wall through the same opening, but one of each sex was often found in close proximity to the other. Measurements made at this time were approximately the same as those made at 19 days: Male, 2.7 to 3 millimeters long by 100μ wide; cordons well developed for a distance of 800μ; cloacal aperture about 218μ from posterior end; spicules and caudal papillae faintly discernible but not well developed. Female, 3.8 millimeters long by 125μ wide; cordons well developed for a distance of 1.4 millimeters; vulva dividing body length in ratio of 3 to 2; anus 225μ from posterior end.

Between the twenty-fifth day and the time when the nematodes became mature, at about 76 days, they were extremely difficult to locate. They had disappeared from the surface of the gizzard but had not yet made any observable tunnels, apparently having penetrated deeper and deeper into the tissue, between the muscle fibers. Females 6.2 millimeters long by 188μ wide were collected at the end of 29 days; the eggs were beginning to form in the ovaries at that time but were still very elementary. The vulva divided the body length in the ratio of 5 to 3; cordons were discernible to a point somewhat posterior to the vulva. Males collected at the end of 61 days were 4.7 millimeters long by 188μ wide; the cordons were discernible to within 880μ of the posterior end of the body; the spicules were well formed, the long, slender spicule, 1.25 millimeters in length, being just six times the length of the short, stout spicule, which measured 208μ. Caudal papillae were well developed. At the end of 76 days both males and females were collected; the tissue reaction was noticeable at that time, a small nodule having formed around the parasites. The males at that time measure 13 millimeters long; the longer spicule is 1.5 millimeters, the shorter spicule 220μ in length; the females are from 15 to 17 millimeters long and embryonated eggs are present in the uteri. Development appears to be complete at this time except for the fact that female specimens collected at later periods, namely, at 8, 8⅔, and 9½ months, exceeded 17 millimeters in length, attaining a maximum size of 22 millimeters.

It is thought probable that the mortality rate is high among the immature specimens of *C. hamulosa* during the period of invasion of the thick, muscular wall of the gizzard. It was found that a comparatively large number of larvae must be ingested by the chicken, in these experimental feedings, in order to obtain an infection. Several of the unsuccessful attempts reported above as negative findings were cases in which only from three to six larvae were fed to the fowl. Others of the negative findings probably do not represent actual noninfection of the chicken but merely failure to locate the larvae during the period when they were buried in the wall and were still so small that they were found only after prolonged microscopical search, if at all. Aside from such considerations, however, the fact that early examinations, that is, up to 25 days after the initial infection, gave positive findings in practically 100 per cent of the experimental feedings, and on the other hand that about one-third of the total negative findings were at a period of two and one-half to four and one-half months after the feeding and thus at a time when the worms would have been fully grown if present, indicates that a certain proportion of the invading nema-

todes never develop to maturity. It is possible that the general state of health of the fowl may be a factor in determining whether the nematodes successfully accomplish this invasion.

As regards the site of invasion, the larvae of *C. hamulosa* appeared to burrow under the corneous lining of the gizzard at its anterior end, near its junction with the proventriculus where the tissues are softest. They were found in that area in the early stages, that is, at 11 days. Later, however, they were well distributed over the surface of the muscular wall of the gizzard and were found at 25 days penetrating the musculi laterali as well as the musculi intermedii. On the other hand, in the experimentally produced infections, the final location of adults, with accompanying tissue damage, was always in the musculi intermedii, in the comparatively soft, thin area on the side of the gizzard opposite the openings of the stomach and intestine.

Table 3 summarizes the rate of development of *C. hamulosa*, the measurements having been made at various stages, as indicated.

TABLE 3.—*Measurements of Cheilospirura hamulosa at various stages in its development*

Part measured	In grasshopper 22 days and later	In chicken at—				
		11 days	16 days		25 days	
			♀	♂	♀	♂
Body length	700μ	1.2 mm	2.5 mm	2 mm	3.8 mm	2.7 to 3 mm.
Body width	40μ to 44μ	64μ	72μ	72μ	125μ	100μ.
Length of cordons			648μ	340μ	1.4 mm	800μ.
Tail length	96μ	144μ	190μ	200μ	225μ	218μ.

Part measured	In chicken at—			
	29 days	61 days	76 days and later	
	♀	♂	♀	♂
Body length	6.2 mm	4.7 mm	15 to 22 mm	9 to 13 mm.
Body width	188μ	188μ	400μ to 625μ	300μ to 320μ.
Length of cordons	4.2 mm	3.8 mm	10 to 15 mm	7.2 to 8.8 mm.
Tail length	240μ	336μ	420μ to 590μ	416μ to 488μ.

DESCRIPTION OF ADULT PARASITE

The descriptions of *C. hamulosa* given in the literature have been lacking in certain important respects. Von Drasche (*9*) furnished good descriptions and illustrations of the head (fig. 6, B) and of the

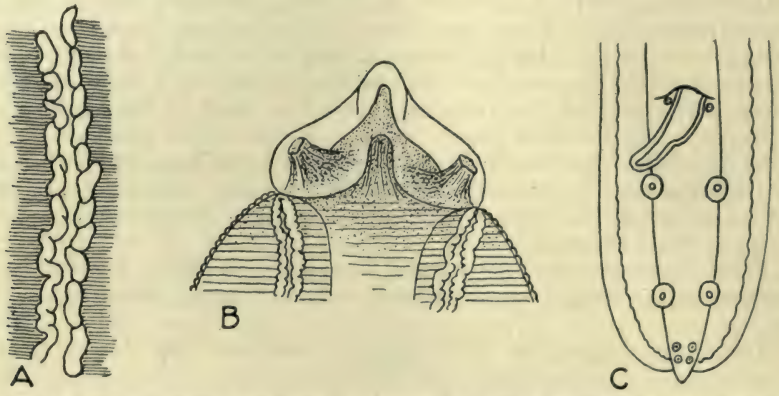

FIGURE 6.—*Cheilospirura hamulosa:* A, Cordon; B, head; C, male tail. After von Drasche, 1884

cuticular cordons (fig. 6, A). The cordons are one of the most important differential characters of this species; the double row of irregularly placed plaques extending posteriorly from the head end for at least two-thirds the length of the body furnish an easily recognizable specific character. Von Drasche explains, however, that on account of the poor condition of the specimens available to him his description of the male tail, especially as regards the preanal papillae, is incomplete. He describes four pairs of postanal papillae, two of which are small and near the tail end, and two other pairs very large and separated from each other by a considerable distance; he pictures (fig. 6, C) an additional small pair just posterior to the cloacal aperture.

FIGURE 7.—Male tail of *Cheilospirura hamulosa*. After Centoscudi, 1911

Centoscudi (*4*) added to these observations made on the male tail, in his description of *Spiroptera perforans*, which species Railliet (*12*) in a critical review of Centoscudi's paper showed to be synonymous with the species, *C. hamulosa*, under discussion here. Centoscudi describes the tail as having two large papillae near its posterior end and eight additional pairs, four of which are preanal and four postanal. His drawing of the tail is shown in Figure 7.

The tail of the male specimens of *C. hamulosa* is tightly coiled; this fact and the density of the underlying structures in the region of the cloacal aperture and immediately anterior to it make discernment of the caudal papillae

very difficult. The writer was able to straighten out the tail ends of eight male specimens and by slight staining with gentian violet and subsequent clearing of the specimens in ethylene glycol was able to bring the papillae into sharp relief. Observations made on these specimens, which were from 9 to 13 millimeters in total length, include the following:

FIGURE 8.—Short spicule of *Cheilospirura hamulosa*

Cloacal aperture situated at a point 416μ to 488μ from the tail end, surrounded by an annular projection, refractive to light, chitinous in appearance. Short, thick spicule (fig. 8), in the shape of a chopping knife, 200μ to 220μ long by 64μ wide as viewed from the dorsal surface. Long, slender spicule 1.6 to 1.8 millimeters in length by 12μ in width. Ten pairs of caudal papillae (fig. 9), of which four small pairs are preanal and six pairs postanal. Of the postanal papillae, three pairs occupy the space which makes up the first third of the length posterior to the cloacal aperture; each pair of the papillae of this group becomes progressively somewhat larger in size than the pair anterior to it. A considerable distance separates this group from the remaining three pairs, which occupy the posterior one-half of the tail length. The middle pair of this posterior group is always the smallest. The arrangement of the six papillae which make up these three pairs varies considerably in different specimens, often being asymmetrical. (Fig. 10.)

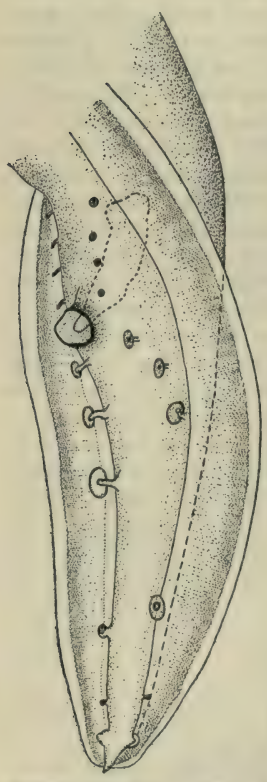

FIGURE 9.—Male tail of *Cheilospirura hamulosa*

In a full-grown female specimen of *C. hamulosa*, 22 millimeters in length, the vulva was located at a point 10 millimeters from the posterior end of the body and was thus slightly posterior to the middle of the body; the anus was about 590μ from the posterior end; eggs dissected from the uterus were 40μ long by 27μ wide.

CHEILOSPIRURA SPINOSA CRAM, 1927

Synonym: *Acuaria* (*Cheilospirura*) species Stafseth and Kotlán, 1925 (*17*)

This parasite was first reported from the ruffed grouse (*Bonasa umbellus*) of Michigan and was subsequently found in that bird in Minnesota, Wisconsin, New York, Massachusetts, New Jersey, and Pennsylvania (*1*). It has been collected from bobwhite quail (*Colinus virginianus*) of Tennessee and of Virginia, which localities are within the range of the ruffed grouse, but has never been found in quail in States farther south, although an ex-

tensive search has been made for it.[4] These findings suggest that the nematode was originally a parasite of the grouse and has spread from it to quail.

In ruffed grouse the percentage of infection was reported by Allen and Gross (*1*) as varying from 14 to 42 per cent in different States. As regards quail, Stoddard [4] found approximately 60 per cent infection of birds from Tennessee, and the writer found approximately 90 per cent infection among quail which were half grown or fully grown, originating from a small area in Virginia, the quail being captive birds of which the original stock had been obtained from the mountainous regions of that State.

C. spinosa is located in the gizzard of the bird host, on the under side of the corneous lining, producing tortuous paths between the lining and the muscular wall. When the nematodes are present in considerable numbers they may produce noticeable damage to the gizzard, as subsequently described.

DEVELOPMENT IN INTERMEDIATE HOST

In attempts to discover possible intermediate hosts of this nematode, feeding the worm's eggs to cockroaches, ground beetles, sow bugs, and crickets gave negative results, whereas in two species of grasshoppers (*Melanoplus femurrubrum* and *M. differentialis*) infestations were successfully produced. Nematodes from quail were first used and the experiments repeated later with nematodes from grouse, with the same results. The larvae which hatched from the nematode eggs migrated from the digestive tracts into the tissues of the grasshopper, chiefly into the muscles of the legs and of the inner surface of the body wall. At the end of 25 days they were loosely encysted and had developed into third-stage larvae, the stage which is infective for the bird host. The larvae uncoiled slowly when the tissues were dissected in water. These third-stage larvae are 850μ long by 40μ wide; the posterior end of the body is bent sharply backward, reversing the curve made by the anterior part of the body (fig. 11), a trait seen also in the third-stage larvae of *C. hamulosa*. (Fig. 4.) The tail end bears four digitiform papillae, three of which, occupying the ventral field, are smaller than the fourth, which is situated in the dorsal field. At the base of this dorsal papilla the cuticle forms a collar with projects slightly as seen in lateral view. (Fig. 12, B.) These tail structures are similar in number and in form to those of *C. hamulosa* (fig. 5, B), but smaller in *C. spinosa* than in *C. hamulosa*. The head end of the larva of *C. spinosa* is provided with two large, lateral lips; at their base the cuticle forms

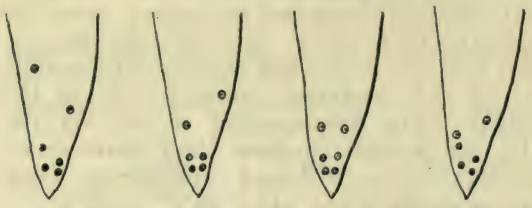

FIGURE 10.—Diagram of variations in arrangement of most posterior group of caudal papillae of *Cheilospirura hamulosa*

[4] H. L. Stoddard examined over 400 quail from the Southeastern States; a report of this study is now in press.

a distinct collar, which projects anteriorly in the dorsal and ventral fields. (Figs. 11 and 12, A.)

DEVELOPMENT IN FINAL HOST

As a result of feeding the third-stage larvae of *C. spinosa* dissected from grasshoppers, the remainder of the life cycle has been artificially produced in the final hosts as follows:

Bobwhite quail: Positive results, 10 cases; negative results, 0 case; controls (all negative), 13. Ruffed grouse: Positive results, 1 case; negative results, 0 case; controls (all negative), 5. In addition, five attempts were made to infect young chickens, all with negative results.

Cross transmission of the parasite from ruffed grouse to quail was accomplished, seven of the experimental infections of quail, as well as that of the ruffed grouse, being produced with larvae which had been developed from material originating from the grouse; in the remaining case of experimental infection of quail the original material was derived from the quail.

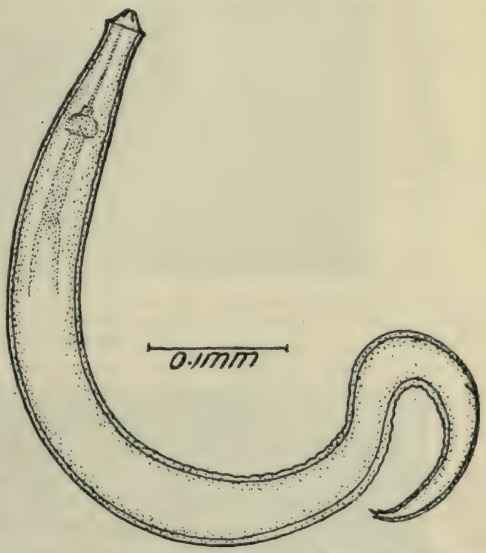

FIGURE 11.—Third-stage larva of *Cheilospirura spinosa* from grasshopper

Observations made in the course of the development of *C. spinosa* in quail include the following: Fourteen days after the feeding of third-stage larvae, the parasites were found underneath the corneous lining of the gizzard as fourth-stage larvae or immature adults. Sexual differentiation was apparent at this time; the larger nematodes, 4.5 mm. long by 120μ wide, displayed a rudimentary vulva and the primordia of the uteri at approximately the middle of the body length. The cordons could be seen extending posteriorly for a distance of 187μ from the head end; the tail was 218μ long. The smaller specimens, apparently males, had not developed sexual characteristics to the extent seen in the females; spicules, caudal alae, and caudal papillae were still lacking. These specimens were 8 millimeters long and 88μ wide; cordons extended for a distance of 125μ from the head end; the tail was 224μ long; primordia of the testes were apparent.

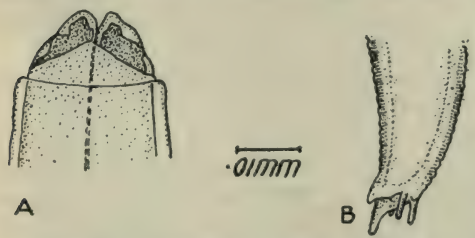

FIGURE 12.—*Cheilospirura spinosa:* A, head end; B, tail end of third-stage larva

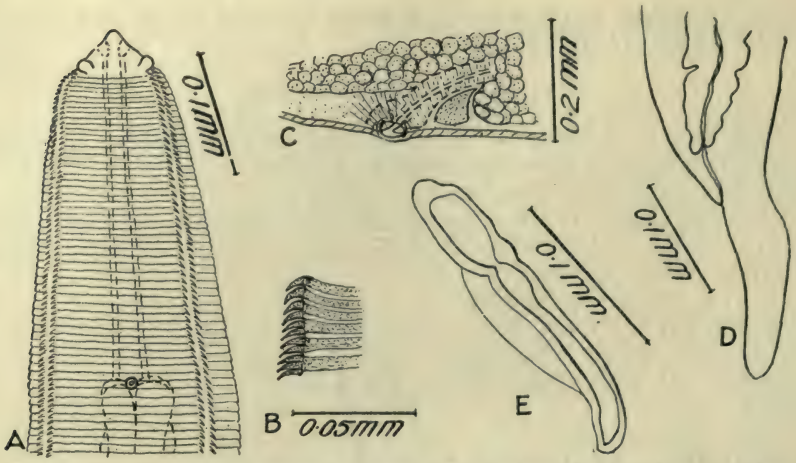

FIGURE 13.—*Cheilospirura spinosa:* A, head end; B, elements of cordon; C, vulva; D, female tail; E, spicule

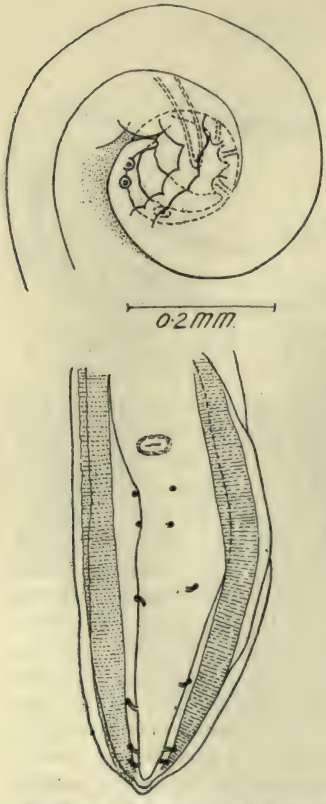

FIGURE 14.—Male tail of *Cheilospirura spinosa,* as seen when coiled and when straightened out

Thirty-two days after the experimental feeding of the bird host, the nematodes had fully developed sexual characteristics; eggs were present in the uteri, but in small numbers and were not yet embryonated. Neither males nor females had reached their full size, however, the males being 8 millimeters long and the females 18 millimeters long at that time. At the end of 45 days, embryonated eggs were being deposited by the females, and the development of both sexes appeared to be complete. The females at that time were 35 millimeters, the males about 12 millimeters long. In ruffed grouse the nematodes attained a greater size, the males being up to 20 millimeters, the females up to 40 millimeters long. The adult characteristics are shown in Figures 13 and 14.

In cases of heavy infestation, both as found in nature and as artificially produced, the gizzard lining may be hemorrhagic and necrotic and the wall flabby (figs. 15 and 16); marked proliferative changes were noted in the gizzard wall in one of the quail, associated with a heavy infection of 84 days' duration. (Fig. 17.)

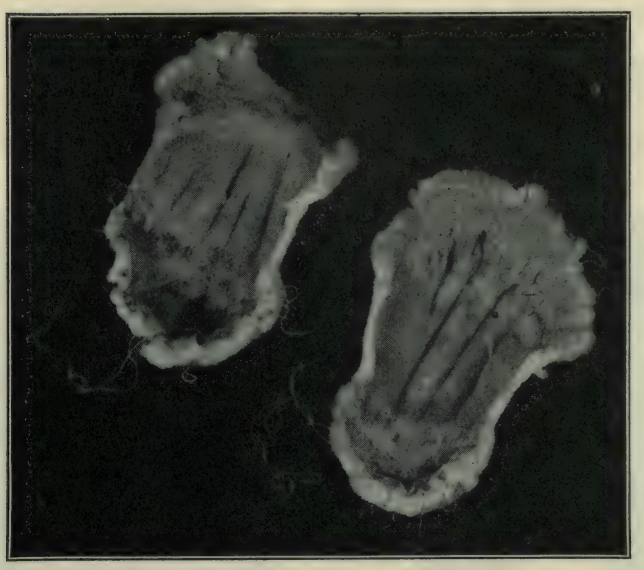

FIGURE 15.—Upper surface of corneous lining of gizzard, showing hemorrhagic necrosis. *Cheilospirura spinosa* protruding from underside. Experimental infection of ruffed grouse

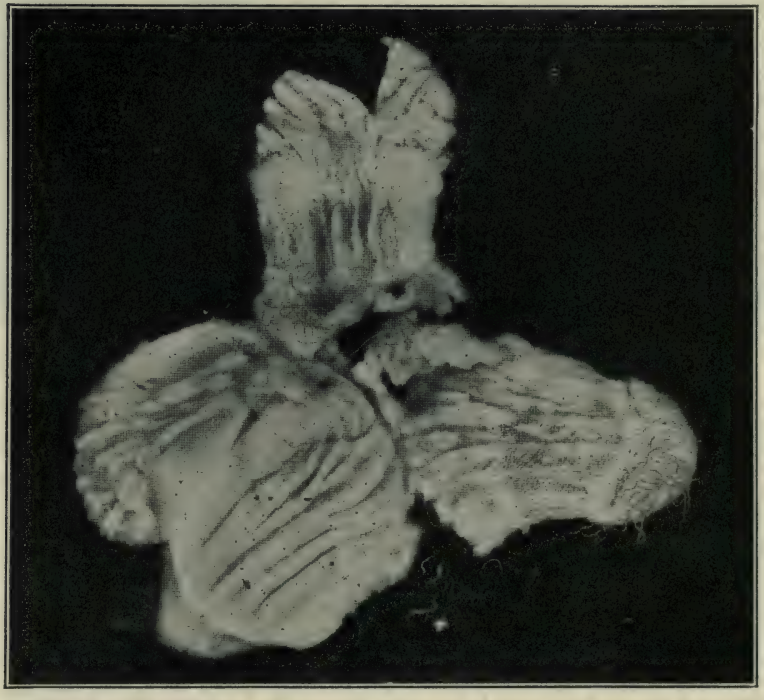

FIGURE 16.—Undersurface of corneous lining of gizzard, and exposed muscular wall, showing *Cheilospirura spinosa* and damage produced by them. Experimental infection of ruffed grouse. Actual size

DISPHARYNX SPIRALIS (MOLIN, 1858) SKRJABIN, 1916 (*16*)

Synonyms: *Dispharagus spiralis* Molin, 1858; *D. nasutus* of Piana, 1897 (*11*); *D. spiralis columbae* Bridré, 1910 (*3*); *Acuaria spiralis* (Molin, 1858) Railliet, Henry, and Sisoff, 1912 (*13*)

The adult forms of these spirurids are short and comparatively thick, white worms, with the body curved or rolled in a spiral.

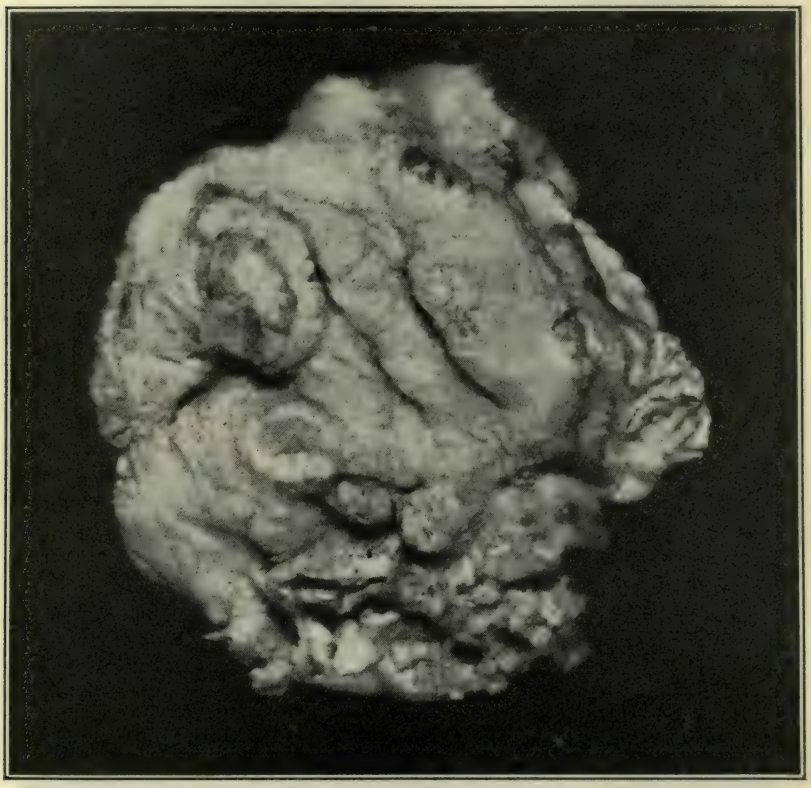

FIGURE 17.—Proliferative changes in gizzard wall of experimentally infected quail, 84 days after infection with *Cheilospirura spinosa*. (Nematodes not to be seen as they were attached to the underside of the corneous lining, which has been removed.) Two times actual size

(Figs. 18 and 19.) Their usual location is the glandular stomach, or proventriculus, where their heads may be deeply buried in the wall. The characteristics of the head end of *D. spiralis* may be seen in Figure 20, and those of the male tail in Figure 21.

This parasite is not of common occurrence in the United States, but its distribution covers a wide territory and a wide range of domestic and game birds. It has been collected from the Hungarian partridge (*Perdix perdix*) in Wisconsin, the ruffed grouse in Wisconsin and in the New England States, the bobwhite quail in New Jersey, the turkey in Maryland, the chicken in Louisiana, the pigeon in Texas, and the guinea fowl in Porto Rico. The parasite is po-

tentially, and in many cases actually, highly pathogenic; in the case of pigeons the parasitic disease may result in high mortality among domestic birds, and in the case of ruffed grouse it has been considered the probable cause of deaths of birds in the wild.

DEVELOPMENT IN INTERMEDIATE HOST

In the search for possible intermediate hosts of *D. spiralis* in the United States, cultures of eggs of the nematodes collected from

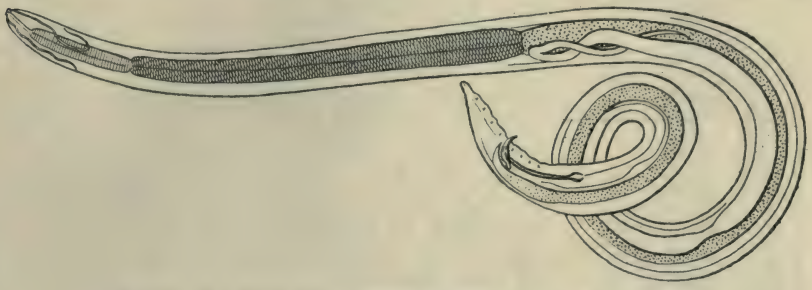

FIGURE 18.—Male of *Dispharynx spiralis*. After Piana, 1897

ruffed grouse were fed to snails, slugs, earthworms, millipeds, grasshoppers, leaf hoppers, crickets, cockroaches, ground beetles, beetle larvae, and isopods (sow bugs). All the results were negative except in the case of the isopods, in two species of which, *Porcellio scaber* and *Armadillidium vulgare*, the eggs hatched, and the larvae continued their development. After four days the larvae were found among the tissues of the body cavity of the isopod, distributed throughout the whole body length. They were outstretched, not coiled, and only very slightly active when removed in a small quantity of water; they were from 176μ to 192μ long by 12μ to 14μ wide at that stage of their development. After 14 days in the isopod the larvae were seen to be about to shed their cuticle, the sheath protruding at both ends of the body, or in some cases to have already shed it, these latter larvae (second stage) being somewhat larger than those still retaining the sheath (first stage). The largest larvae were at that time from 1 to 1.2 millimeters in length by 50μ to 56μ in width; this width being comparatively great, they presented a stocky appearance, which was accentuated by the fact that the head end was very bluntly rounded. There were no lips at the mouth; the total length of the esophagus (including the pharynx) was 300μ to 330μ; the excretory pore was prominent in live specimens, being situated about 85μ to 90μ from the head end. The tail was short, tapering very little but with a small point at the end. The larvae were very inactive at that stage, merely giving little jerky movements, chiefly with the anterior part of the body.

FIGURE 19.—Female of *Dispharynx spiralis*. After Piana, 1897

Development of the larvae in the intermediate host was completed within 26 days; that is, the larvae reached the infective third

stage. There is no evidence that these larvae were encysted or even coiled, as is often the case with third-stage spirurid larvae, in the tissues of the arthropod host; they emerged from the tissues very quickly when the isopod was partially dissected in a small quantity of water. This third-stage larva is from 2.9 to 3.2 millimeters in length by 65μ to 85μ in maximum width. The head end tapers little or not at all, having a blunt appearance; there are two small, pointed lips and four submedian papillae. (Fig. 22, A.) There is no evidence of cordons such as are present in the adult form of the nematode. A slender, distinct pharynx, 60μ to 70μ long, is followed by a 2-part esophagus; the first part, the muscular portion, is 275μ to 320μ long; the second part, the glandular portion, is about 720μ long; the excretory pore is 175μ to 190μ from the head end. The tail is short (fig. 22, B), the anal aperture being 135μ to 145μ from the posterior end. The rectal glands are very conspicuous. The tail end is without spines or papillae, but the tip is rounded and slightly set off by a constriction from the region anterior to it.

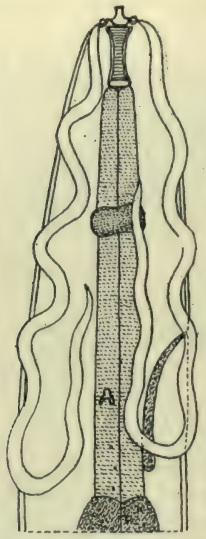

FIGURE 20.—Head end of *Dispharynx spiralis*. After Seurat, 1917

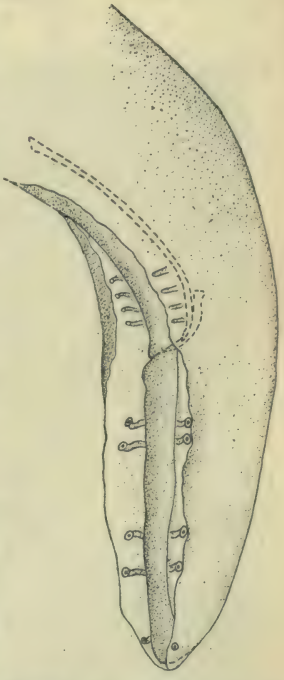

FIGURE 21.—Male tail of *Dispharynx spiralis*

DEVELOPMENT IN FINAL HOST

Third-stage larvae of *D. spiralis* recovered from the two species of isopods, the isopods having been fed on eggs of the nematode collected from the ruffed grouse, were fed to bird hosts, with the results shown in Table 4.

TABLE 4.—*Development of Dispharynx spiralis in various bird hosts*

Host	Positive results		Negative results	Controls (all negative)
	Birds infected after feeding	Nematodes developed per bird	Birds not infected after feeding	
	Number	*Number*	*Number*	*Number*
Ruffed grouse	1	[1] 10	0	5
Bobwhite quail	3	2–12	0	6
Pigeon	3	5–9	0	2
Chicken	0	0	7	19

[1] Of these nematodes 5 were males and 5 females.

The nematodes were fully developed, the female worms being gravid and their eggs embryonated, 27 days after the ingestion of the larvae by the bird host. In all cases the adult nematodes were concentrated in one area of the proventriculus, and this area was thickened and ulcerated. The heads of the worms were found tightly buried in the wall and on being forcibly extracted were seen to be stained with blood. None of the birds showed serious clinical effects from the infection, possibly because of the small number of nematodes present in each case.

The explanation of the negative results in the case of the experimental feedings of chickens is not apparent. From 2 to 20 larvae were fed in these cases, the larvae originating from several different lots of isopods (all specimens of *Porcellio scaber*), and being fed to young chicks ranging in age from 6 to 29 days at the time of feeding. Specimens collected from the chicken in natural infestations were compared with those from the ruffed grouse, and no morphological differences of importance were to be seen. In these experiments, however, all the material originated from the ruffed grouse, and it is possible that a biological strain has become established in that host and other game birds, the game birds being new hosts, if one may judge by the fact that the records of collection of the parasites from them are all of recent date as compared with those of collections from domestic fowls, which are of many years' standing. The chicken may thus have become much more resistant to infection with this parasite than are game birds.

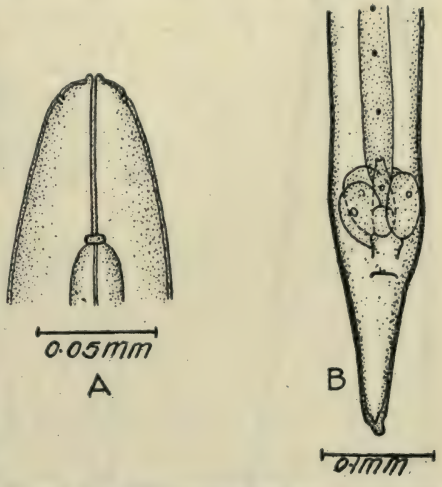

FIGURE 22.—Third-stage larva of *Dispharynx spiralis*: A, head; B, tail

SEUROCYRNEA COLINI (CRAM, 1927) CRAM, 1930

Synonym: *Cyrnea colini* Cram, 1927 (*5*). The genus Cyrnea Seurat, 1914 (*14*) has been changed to Seurocyrnea Strand, 1929 (*19*). Strand points out that the former name was preoccupied by Deshayes in 1858, the latter writer giving a misspelling for Cyrena of Lamark and this error invalidating the name Cyrnea for future use

Seurocyrnea colini is of common occurrence in bobwhite quail of the Southeastern States. It has also been collected from that host in New Jersey and from *Colinus virginianus texanus* in the Philadelphia Zoological Gardens; it occurs in the turkey (*Meleagris gallopavo*) of Georgia, in the prairie chicken (*Tympanuchus americanus*) of Wisconsin, and in the sharp-tailed grouse (*Pedioecetes phasianellus*) of Wisconsin and Montana. As yet it has not been reported from any country other than the United States.

The nematode is located in the wall of the proventriculus, at its junction with the gizzard; it burrows into the wall at this site,

but no pathological condition has been found which was definitely attributable to its presence.

DEVELOPMENT IN INTERMEDIATE HOST

The writer undertook an investigation of the life history of *S. colini* as part of a study of the parasites of quail conducted by the cooperative quail investigation (report by H. L. Stoddard, now in press). The nematode is of frequent occurrence in Georgia and northern Florida, and attempts were made there to infect various ground beetles and dung beetles, with no success. The study was resumed at a later date in Washington, D. C., specimens of the parasite having been obtained from quail shipped from Mississippi. Grasshoppers and sow bugs gave negative results in feeding experiments, but in the case of cockroaches (*Blattella germanica*) experimental infections were successfully produced. This species of cockroach is the one commonly found around habitations, but it is probable that other cockroaches, such as occur in fields and woods, are the forms more commonly serving as hosts.

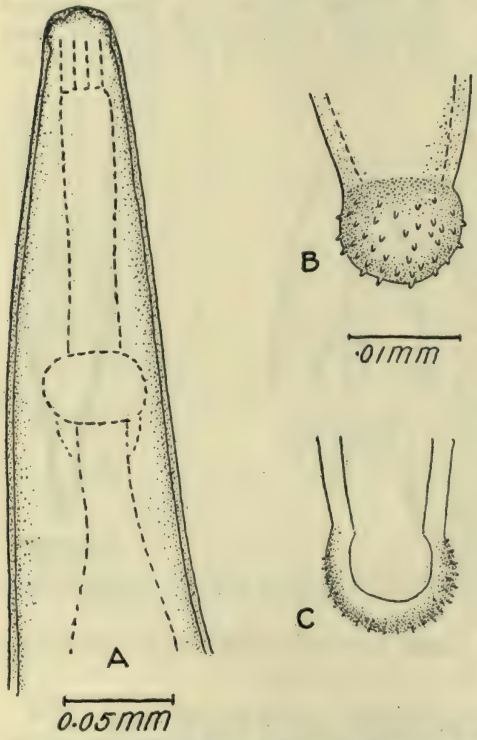

FIGURE 23.—Third-stage larva of *Seurocyrnea colini*: A, head; B, tail in surface view; C, tail in optical section

The larvae which hatch from the eggs of *S. colini* leave the digestive tract of the cockroach and develop in the body cavity. They do not appear to encyst but develop to third-stage larvae among the tissues, from which they quickly emerge when the cockroach is dissected. These larvae are the largest and the most active of all the third-stage spirurid larvae considered in this study. They can readily be seen with the naked eye, being 3.2 to 3.3 mm. long by approximately 100μ wide. The head end is bluntly rounded; it is without lips, but the structure underlying the cuticle suggests the primordia of lips. (Fig. 23, A.) The pharynx is 24μ deep; the first part of the esophagus 225μ, the second part 1.2 millimeters long. The anus is situated 90 to 95μ from the posterior end. The tail ends in a small, bulbous swelling which is covered with minute, refractive points. (Figs. 23, B and C.)

The larvae of *S. colini* are apparently fully developed at the end of 18 days in the cockroach, as they do not change in size or appear-

ance between the eighteenth and the forty-fifth days; however, it is only at the end of a 45-day period that their infectivity for the final host has been tested, with the results given in Table 5.

DEVELOPMENT IN FINAL HOST

Third-stage larvae of *S. colini* were fed to the following birds with the results indicated in Table 5.

TABLE 5.—*Development of Seurocyrnea colini in various bird hosts*

Host	Killed after number of days shown below	Results	Controls (all negative)
Quail:			*Number*
No. 1	13	Positive; 12 specimens	9
No. 2	30	Negative	9
No. 3	41	Positive; 18 specimens	9
Chicken:			
No. 1	13	Positive; 4 specimens	10
No. 2	30	Negative	10
Turkey	30	....do	0

The specimens collected from the quail and from the chicken at the end of 13 days were composed of fourth-stage larvae and immature adults. The former were 4.2 millimeters in length at that time; the head structures were not fully developed, and the bulbous swelling was still present on the tail. Of the immature adults which were also present, the males were 5.5 millimeters long; the caudal alae and the caudal papillae were well formed, there being 10 pairs of the latter, 9 pairs of which were situated laterally and 1 pair, just anterior to the cloacal aperture, situated slightly more ventrally. The females were 6.3 millimeters long; the location of the vulva was 520μ, and that of the anus 175μ, from the posterior end.

The specimens collected from the quail 41 days after the experimental feeding comprised 13 females and 5 males. When collected they were stained with blood pigment, especially in the case of the males; the pigment was most noticeable in the head region. The males were from 7 to 8 millimeters long by 175 to 200μ wide; the spicules were 2 millimeters and 384μ long, respectively. Development was apparently complete at that time; in a considerable number of specimens collected from natural infestations the males were 6 to 10 millimeters long, with the spicules 2 millimeters and 365 to 400μ long, respectively. The females, at the end of the 41-day period, were from 13 to 15 millimeters long; the eggs in the uteri were embryonated and were shown to be infective by experimental feeding to cockroaches, with subsequent development of third-stage larvae in that host. It is probable that the females increase somewhat in size after the forty-first day, as specimens collected in natural infestations had a maximum length of 18 millimeters. The anus in adult female specimens was 260 to 332μ from the tail end, and the vulva was 760 to 960μ anterior to the anus. (Fig. 25, B and C.)

The head structures of adult specimens of *S. colini* are very distinctive. (Fig. 24.) There are four lips, of which those situated dorsally and ventrally are deeply divided into two parts, in such a manner that in lateral view the head appears to bear four conspicuous papillae. Each of the four parts of these lips bears on its outer edge a prominent thumblike extension. The lateral lips are very large; each bears two digitiform processes on its inner surface and two lateral winglike expansions which project into the median groove of the dorsal and ventral lips in such a manner as to give the appearance in some views of being processes from the latter lips.

The male tail (fig. 25, A) is also distinctive, the caudal alae being short and wide, with coarse, transverse striations. The number and position of the caudal papillae vary slightly. Nine or ten pairs may be present, or occasionally 9 papillae on one side and 10 papillae on the other side; they are usually arranged in two practically straight rows, but in some specimens one pair, or occasionally an unpaired papilla, is situated more ventrally and just anterior to the cloacal aperture.

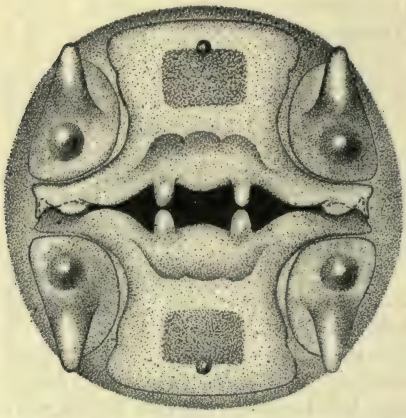

FIGURE 24.—Head of *Seurocyrnea colini*: en face view; semidiagrammatic

The experimental infection of a chicken here described constitutes the first record of the collection of *S. colini* from that host. The chicken was only 2 days old when fed.

That the three negative results, namely, those in a quail, chicken, and turkey, were all cases in which the observations were made 30 days after the feeding, whereas the three positive results, namely, those in two quail and a chicken, were observations made at 13 days in two cases and at 41 days in one case, probably represents merely a coincidence. But the possibility is suggested that at 30 days the nematodes are not in the same location as at an earlier and again at a later date, and that this fact may account for their not being found in those cases. Additional experiments are desirable in order to make further observations at the 30-day period.

SUMMARY

The present study furnishes information concerning the life histories of six nematodes of the superfamily Spiruroidea, occurring in birds; three families, namely, the Spiruridae, Acuariidae, and Tetrameridae, are represented. In one case, involving a member of the Spiruridae, *Gongylonema ingluvicola*, the adult nematodes were developed experimentally in a chicken and a rabbit from larvae found in natural infestations in the dung beetles *Phanaeus vindex* and *Copris minutus*. In the other cases the entire life cycle was artificially produced. For a second member of the Spiruridae, *Seurocyrnea colini*, the cockroach (*Blattella germanica*) was found capable of serving as intermediate host. Of the Acuariidae, two species of

Cheilospirura, *C. hamulosa* and *C. spinosa*, were developed in grasshoppers (*Melanoplus femurrubrum* and *M. differentialis*) as intermediate hosts, and a species of Dispharynx, *D. spiralis*, was developed in isopods (*Porcellio scaber* and *Armadillidium vulgare*). Of the Tetrameridae, *Tetrameres americana* was developed in grasshoppers (*Melanoplus femurrubrum* and *M. differentialis*).

Experimental development of the adult spirurids was accomplished in the following bird hosts: *Tetrameres americana* in the chicken (*Gallus gallus*), domestic duck (*Anas platyrhyncha domestica*), domestic pigeon (*Columba livia domestica*), bobwhite quail (*Colinus virginianus*), and ruffed grouse (*Bonasa umbellus*); *Cheilospirura hamulosa* in the chicken; *C. spinosa* in bobwhite quail and ruffed grouse; *Dispharynx spiralis* in bobwhite quail, ruffed grouse, and the domestic pigeon; and *Seurocyrnea colini* in bobwhite quail and, as immature specimens, in the chicken.

Differential characteristics of the third-stage larvae of the five species of spirurids developed experimentally in the arthropods include size, activity, and encystment. The size of the larvae varies

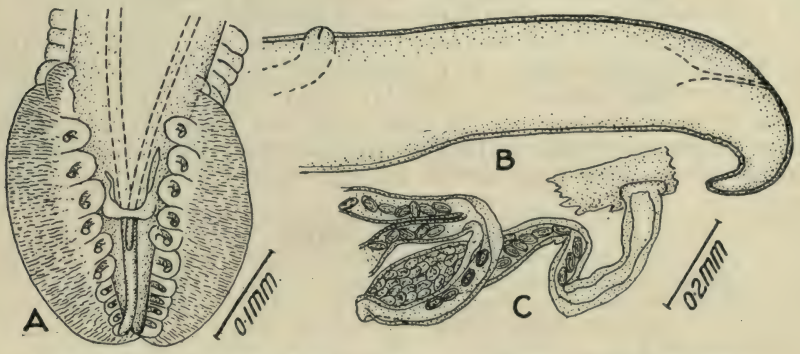

FIGURE 25.—*Seurocyrnea colini:* A, male tail; B, female tail; C, ovejector

greatly, the length being in the case of *Cheilospirura hamulosa* 700μ, in the case of *C. spinosa* 850μ, in the case of *Tetrameres americana* 1.8 to 1.9 mm., in the case of *Dispharynx spiralis* 2.9 to 3.2 mm., and in the case of *Seurocyrnea colini* 3.2 to 3.3 mm. The larger the larvae, the greater the activity shown by them when the intermediate host is dissected; those of *D. spiralis* and *S. colini* are outstretched and emerge from the tissues quickly, crawling and swimming with great agility; those of *T. americana* are coiled rather tightly but soon uncoil and become fairly active; those of *C. hamulosa* and *C. spinosa* on the other hand are tightly coiled and comparatively inactive for a considerable period and seldom become completely outstretched under such conditions. The three smallest larvae, those of *C. hamulosa*, *C. spinosa*, and *T. americana*, all of which are in grasshoppers, are contained in thin-walled cysts, but the larger larvae, those of *D. spiralis* in isopods and those of *S. colini* in cockroaches, appear to be unencysted in the tissues of those hosts.

As regards the length of time for development in the intermediate host, the following observations were made: The infectivity of the larvae for the final host was demonstrated as early as 22 days after

artificial infection of the arthropod with *C. hamulosa*, 25 days after infection with *C. spinosa*, and 26 days after infection with *D. spiralis*. With *S. colini* infectivity was demonstrated only at the end of 45 days, but the larvae appeared morphologically as fully developed on the eighteenth day as on the forty-fifth day. The infectivity of *T. americana* was demonstrated after a 42-day period, but it is thought probable that a shorter period would suffice.

With reference to the length of the period of development in the final host, before maturity is reached, *D. spiralis* matured in 27 days, *S. colini* in 41 days, *T. americana* in 45 days, *C. spinosa* in 45 days, and *C. hamulosa* in 76 days. The length of this period of development appears to be correlated with the degree to which the nematodes penetrate the tissues of the final host and, when deep penetration occurs, to be correlated also with the density of the tissue. *D. spiralis* does not penetrate, except for the head end of the worm, which is buried in the mucosa of the proventriculus; the penetration of *S. colini* is shallow and the tissue soft, at the junction of the proventriculus and gizzard; the penetration of *T. americana* is deep but appears to take place through the canals of the glands of Lieberkuehn and to be therefore comparatively easy; that of *C. spinosa* is shallow but through dense tissue, namely, the corneous layer of the gizzard; and finally, the penetration of *C. hamulosa* is both deep and through very dense tissue, that of the muscular wall of the gizzard.

The greatest damage to the final host was observed during the period of invasion of the wall of the digestive tract by the nematodes; clinical effects were most severe and the mortality highest at that stage.

LITERATURE CITED

(1) ALLEN, A. A., and GROSS, A. O.
1926. RUFFED GROUSE INVESTIGATIONS, SEASON OF 1925–26. Amer. Game Protect. Assoc. Bul. 15 (4): 81–84, illus.

(2) BAYLIS, H. A.
1929. A MANUAL OF HELMINTHOLOGY, MEDICAL AND VETERINARY. 303 p., illus. London.

(3) BRIDRÉ, J.
1910. UN DISPHARAGE DU PIGEON. Bul. Soc. Path. Exot. 3: 38–39.

(4) CENTOSCUDI, C.
1911. OSSERVAZIONI ANATOMO-PATOLOGICHE RIGUARDANTI UNA NUOVA SPECIE DI SPIROPTERA DEL POLLO. Zool. Anz. 37: 394–400, illus.

(5) CRAM, E. B.
1927. BIRD PARASITES OF THE NEMATODE SUBORDERS STRONGYLATA, ASCARIDATA, AND SPIRURATA. U. S. Natl. Mus. Bul. 140, 465 p., illus.

(6) ———
1928. NEMATODES OF PATHOLOGICAL SIGNIFICANCE FOUND IN SOME ECONOMICALLY IMPORTANT BIRDS IN NORTH AMERICA. U. S. Dept. Agr. Tech. Bul. 49, 10 p., illus.

(7) DIESING, K. M.
1851. SYSTEMA HELMINTHUM. v. 2, 588 p. Vindobonae.

(8) ———
1861. REVISION DER NEMATODEN. Sitzber. Akad. Wiss. Wien, Math. Naturw. Kl. (1860) 42: 595–736, illus.

(9) DRASCHE, R. VON
1884. REVISION DER IN DER NEMATODEN-SAMMLUNG DES K. K. ZOOLOGISCHEN HOFCABINETES BEFINDLICHEN ORIGINAL-EXEMPLARE DIESING'S UND MOLIN'S. Zool.-Bot. Gesell Wien, Verhandl. (1883) 33: 107–118. 193–218, illus.

(10) MOLIN, R.
1858. PROSPECTUS HELMINTHUM, QUAE IN PRODROMO FAUNAE HELMINTHOLOGICAE VENETIAE CONTINENTUR. Sitzber. Akad. Wiss. Wien, Math. Naturw. Kl. 30 (14) : 127–158.
(11) PIANA, G. P.
1897. OSSERVAZIONI SUL DISPHARAGUS NASUTUS RUD. DEI POLLI E SULLE LARVE NEMATOELMINTICHE DELLE MOSCHE E DEI PORCELLIONI. Soc. Ital. Sci. Nat. Atti. [Milano] 36 : 239–262, illus.
(12) RAILLIET, A.
1911. OBSERVATIONS ANATAMO-PATHOLOGIQUES SUR UNE NOUVELLE ESPÉCE DE SPIROPTÈRE DU POULET. (Par. C. Cento[scudi].) (Abstract) Rec. Méd. Vét. 88 (11) : 391.
(13) ——— HENRY, A., and SISOFF, P.
1912. SUR LES AFFINITÉS DES DISPHARAGES (ACUARIA BREMSER), NÉMATODES PARASITES DES OISEAUX. Compt. Rend. Soc. Biol. [Paris] (Année 64) 73 : 622–624.
(14) SEURAT, L. G.
1914. SUR UN NOUVEAU PARASITE DE LA PERDRIX ROUGE. Compt. Rend. Soc. Biol. [Paris] (Année 66) 76 : 390–393, illus.
(15) ———
1916. DISPHARAGES D'ALGÉRIE. Compt. Rend. Soc. Biol. [Paris] (Année 68) 79 : 934–938, illus.
(16) SKRJABIN, K. J.
1916. NEMATODES DES OISEAUX DU TURKESTAN RUSSE. Ann. Mus. Zool. St. Petersburg (1915) 20 : 457–557, illus.
(17) STAFSETH, H. J., and KOTLÁN, A.
1925. REPORT OF INVESTIGATIONS ON AN ALLEGED EPIZOOTIC OF RUFFED GROUSE IN MICHIGAN. Jour. Amer. Vet. Med. Assoc. (n. s. 20) 67 : 260–267, illus.
(18) STOSSICH, M.
1890. ELMINTI VENETI RACCOLTI DAL DR. ALESSANDRO CONTE DE NINNI. Bol. Soc. Adriat. Sci. Nat. Trieste 12 : [49]–56.
(19) STRAND, E.
1929. ZOOLOGICAL AND PALAEONTOLOGICAL NOMENCLATORIAL NOTES. Latvijas. Univ. Sist. Zool. Inst. Riga Darbi No. 29, pp. 1–29. [Reprinted from Acta Univ. Latviensis 20 : 1–29, 1929.]

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CHARACTER OF THE COLLOIDAL MATERIALS IN THE PROFILES OF CERTAIN MAJOR SOIL GROUPS

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CONTENTS

	Page		Page
Introduction	1	Character of podsol colloids	11
Previous work	2	Character of laterite and lateritic colloids	16
Description of soil samples	3	Comparison of colloids from different soil groups	19
Mechanical and chemical composition of soils	5	pH values of electrodialyzed colloids	20
Methods of study of colloidal materials	7	Summary	22
Character of pedocal colloids	9	Literature cited	23

INTRODUCTION

Considerable information is available regarding the composition and properties of colloids from soils of widely differing character. Emphasis has been placed on the study of colloids from the more important soil types, and such studies have for the most part been confined to materials isolated from one, or at most two, horizons of a profile. Some investigations have, however, increased the scope of this work to include a few complete profiles. In recent years much emphasis has been placed on the character of soil materials in the various horizons of complete soil profiles and on the nature of the processes whereby horizon development takes place. However, little attention has been given to the effect of soil-making processes on the character of the resulting colloids in various horizons of the profiles. In the present study data are obtained which indicate the character of the colloidal materials developed throughout the profile as a result of a dominating influence of one of the major soil-making processes in developing a typical profile. Three of these soil-making processes, which have been widely recognized, are calcification, podsolization, and lateritization. These processes lead respectively to the formation of pedocals, podsols, and laterites.

The general plan of the investigation was to secure typical profiles of the several major soil groups and to isolate and study colloidal material from each of the horizons. Chemical analyses and

a study of properties were made of each in order to bring out as well as possible similarities and differences in the colloidal materials which are characteristic of the various horizons and of the different soil groups.

PREVIOUS WORK

Very few data are available regarding the character of the colloidal materials in typical profiles of any of the major soil groups mentioned. Most of the soil-colloid studies previously made have been done without any reference to the processes by which the soils were developed and, with few exceptions, without consideration of the horizon in the soil profile from which the sample was taken. Similarity of colloidal materials in various horizons of most profiles appears to be the general rule. This is indicated by the study of materials from a considerable number of soils and subsoils by Robinson and Holmes (*30*).[1] A detailed study by Holmes (*17*) of several complete profiles of the Leonardtown soil series from different localities led to a similar conclusion, as does also the work on the Cecil, Chester, and Miami soil series by Holmes and Edgington (*18*).

Denison (*11*) gives the chemical composition of colloids from several horizons of profiles of widely diversified character. Included in this group are a podsol profile from Michigan and a chernozem from South Dakota. The horizons of the podsol reported are the A_1, B_3, and C_2. The parent material is highly calcareous. In this profile the colloids are fairly uniform in the major elements of composition. The silica-sesquioxide ratio is, however, somewhat lower in the B_3 horizon than in the A_1 or C_2. The chernozem profile shows about the same silica-sesquioxide relationship within the profile as that shown by the podsol. Deep horizons of certain piedmont soils show unusually low silica-sesquioxide ratios. The work of McCool (*23*) with certain Michigan soils showed no very marked differences in the colloid throughout the profile, although some of these are podsolic in character. There was, however, a tendency toward higher silica content and higher heat of wetting in the colloids of the B horizons than in the colloids either above or below this layer.

Although similarity of colloids from different horizons of a particular profile appears to be the rule for many widely diversified soils, instances have been reported of colloids from profiles where certain horizons show rather wide differences in character of colloid. In his exhaustive report on the forest soils of northern Sweden, many of which are true podsols, Tamm (*31*) gives the chemical composition of fractions below 0.002 millimeter in diameter for the bleached layers and for the ortsteins of two of these soils. These fractions may be assumed to consist essentially of colloidal material. If the silica-sesquioxide ratios be taken as indices of the major features of chemical composition, considerable differences are noted in the horizons. Calculations made from Tamm's data show these ratios to be 3.44 and 4.16 for fractions from the bleached layers, and 2.63 and 2.10 for fractions from the corresponding ortsteins.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

The data available regarding the colloids of true laterites are too fragmentary to allow of any conclusion regarding colloid variation throughout the profile. The same is true of the pedocal group of soils. There is, however, some evidence that colloidal $CaCO_3$ is relatively inert in properties.[2]

DESCRIPTION OF SOIL SAMPLES

The soil samples used in the present studies were collected by various members of the field staff of the soil survey division of this bureau under the general direction of C. F. Marbut. General characteristics of the various soil classes and detailed descriptions of the profiles studied follow. One pedocal, two podsols, and three lateritic soils are discussed.

The calcification process results in the formation of the pedocal[3] group of soils, an important division of which includes the chernozems. These are found in regions of moderate to low rainfall and are characterized by the accumulation of calcium carbonate in the lower horizons. Profile No. 1 is a specimen of this class. It is an Amarillo silty clay loam which is representative of the southern chernozems. Samples were collected by E. H. Templin 1 mile east of Nash, Potter County, Tex. Horizon 1[4] is of rich-brown color with a faint tint of red; horizon 2 is dark brown, slightly lighter in color than horizon 1; horizon 3 is of yellowish-brown color; horizon 4 shows a marked contrast in color to the above horizons, being a reddish yellow; horizon 5 is yellowish white with a very faint pink shade; and horizon 6 is somewhat more pink than horizon 5.

The general character of profiles of the so-called podsol soils has been widely discussed by soil investigators. The podsols are forested soils occurring in northern latitudes. A typical profile of this class of soils may be summarized as follows: The surface layer consists of a covering of decomposing leaves and other organic remains which are distinctly acidic in character. Below this is a bleached layer usually gray in color and of lighter texture than the layer beneath it. This layer is commonly known as bleicherde. It is underlain by a rust-colored or brown layer which in many places takes the form of a hardpan and is commonly referred to as the ortstein, or the orterde if not indurated. The cementing material may be of high iron content, high in organic matter, or a mixture of relatively large quantities of each. Below the ortstein is the parent material.

Two typical podsol profiles were obtained for study. Detailed descriptions of these profiles are as follows: Profile No. 2 is a Superior fine sandy loam. It was collected by W. J. Geib near Bayfield, Wis., from a wood lot of virgin soil. The A_0 horizon, 0 to 3 inches in

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[2] McCool, M. M., and Wheeting, L. C. STUDIES ON THE COLLOIDAL MATERIAL OF CERTAIN SOIL PROFILES IN MICHIGAN. Amer. Soil Survey Assoc. Rpt. Ann. Meeting 5, Bul. 6, v. 2, p. 122–126c, illus. [Mimeographed.]

[3] The term "pedocal" has been used by Marbut (*25*) to designate those soils which have "fully developed profiles in which lime carbonate is found in some horizon of the solum in higher percentage than in the parent geological formation beneath."

[4] The term "horizon" is used here to designate a layer in the profile different in some respect from the layers above and below it and has no reference to the usual differentiation of the profile into the conventional A, B, and C horizons. This is true in general in this bulletin except where such designations are used.

depth, consists of partly decayed leaves and other organic matter and has a dark-brown color. The A_1 horizon occurs from a depth of 3 to 8 inches; its color is gray with a very slight pink tint. The B horizon, between depths of 12 and 30 inches, ranges from light to dark coffee brown in color and is compactly cemented. The C horizon, extending from a depth of 30 to 40 inches, is of pinkish-gray color. It rests on heavy red clay.

Profile No. 3 is a Beckett loam collected by W. J. Latimer in a virgin-forest area 1 mile west of Washington, Mass. The A_0 horizon, from 0 to 6 inches, is of dark-brown color and contains a large amount of leaf mold and roots. The A_1 horizon, from 6 to 11 inches, is essentially gray in color but contains some brown spots. The B_1 horizon is a thin dark-brown or coffee-colored layer, extending from a depth of 11 to 13 inches. The B_2 horizon extends from a depth of 13 to 24 inches and is yellowish brown, grading to pale yellowish brown. Both the B_1 and B_2 horizons are friable. The C horizon, or parent material, taken between depths of 24 and 36 inches, is of yellowish-gray color mottled and streaked with brown.

Laterite soils consist primarily of hydrated oxides or hydroxides of iron or alumina, or both, in the upper horizons. In typical profiles, according to Harrassowitz (*14*), this material is underlain first by a mottled zone and then by a layer of kaolin or kaolinlike material above the parent rock. In general, lateritic soils are characterized by a decrease in the silica-sesquioxide ratio from that existing in the parent rock.

Typical laterite profiles are not easily obtainable. In the present case it was necessary to use material not entirely typical in a complete profile, but by the use of three profiles the various classes of materials are represented. Profile No. 4 is a Davidson clay loam soil, lateritic in character, collected by R. C. Jurney, 9 miles north of Greensboro, N. C. Horizon A is 0 to 9 inches in depth, and its color is slightly reddish brown. The B_1 horizon, extending from 9 to 36 inches in depth, is a deep-red heavy brittle clay. Below this is the B_2 horizon, between 36 and 60 inches, which is light-red friable crumbly clay. The C horizon, which lies below 60 inches, is an ocherous-yellow, black, and reddish-brown decomposed diorite rock.

Profile No. 5 is a ferruginous laterite which was obtained near Preston, Cuba. The sample was collected through the courtesy of the United Fruit Co. from an area previously located by H. H. Bennett of this bureau. The first horizon, from 0 to 12 inches, is very dark-red friable clay material containing a few concretions. A second horizon, extending from a depth of 40 to 60 inches, is reddish yellow and of about the same texture as the horizon above.[5] A third horizon, from 100 to 144 inches, is almost identical in color and texture with the first horizon.

Profile No. 6 is an aluminous laterite from a bauxite mine at Bauxite, Ark. This profile can not, strictly speaking, be regarded as a soil since an overburden of some 30 to 40 feet of transported material had been removed, material which had no particular rela-

[5] A communication from C. F. Marbut states that in this locality material similar to that of the second horizon usually persists to an indefinite depth.

tion to the profile of interest for the present work. However, this profile contains material similar, in chemical composition at least, to profiles of typical laterites found in certain parts of the world.

MECHANICAL AND CHEMICAL COMPOSITION OF SOILS

In order to obtain more adequate information regarding the character of the soils which were to serve as sources of the colloids, mechanical and chemical analyses were made. Mechanical analyses were made by the method in use in this bureau (*28*). The results are given in Table 1. Chemical analyses were made by well-authenticated methods for total constituents, methods which have long been in use in this bureau. These analyses are given in Table 2.

TABLE 1.—*Mechanical analyses of soils*[1]

Profile No.	Soil series	Depth	Horizon	Fine gravel, 2.0–1.0 mm.	Coarse sand, 1.0–0.5 mm.	Medium sand, 0.5–0.25 mm.	Fine sand, 0.25–0.1 mm.	Very fine sand, 0.1–0.05 mm.	Silt, 0.05–0.005 mm.	Clay, <0.005 mm.	Inorganic in colloid, <0.002 mm.	Loss on treatment with H_2O_2
		Inches		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	Amarillo	0–5	1	0.0	0.2	0.3	2.6	12.1	55.1	27.6	23.9	2.0
		10–20	2	.0	.1	.2	1.9	8.3	41.0	47.4	42.8	1.1
		30–40	3	1.0	.5	.4	1.6	6.9	45.2	43.8	37.6	.5
		54–64	4	.1	.3	.4	3.4	16.6	41.2	37.9	34.6	.3
		70–75	5	.1	.4	.4	2.2	9.2	34.1	53.4	35.9	.2
		96–100	6	.2	.2	.3	2.1	12.2	41.0	44.0	31.3	.0
2	Superior	0–3	A_2	.3	2.9	4.3	24.7	7.3	16.8	3.0	1.5	40.6
		3–8	A_1	.2	2.0	7.5	52.5	12.5	20.1	4.0	1.6	1.3
		12–30	B	7.1	34.7	33.6	13.5	.8	2.0	7.1	4.9	1.2
		30–40	C	1.5	13.8	50.4	28.6	.9	1.6	3.1	2.6	.2
3	Beckett	0–6	A_0	2.1	7.2	5.6	17.4	15.1	18.6	2.6	.9	31.3
		6–11	A_1	2.6	5.9	7.2	23.2	18.3	33.8	7.0	3.9	2.0
		11–13	B_1	2.3	5.3	6.7	21.6	16.7	28.7	9.6	5.8	9.1
		13–24	B_2	3.1	5.5	6.9	21.2	18.4	30.2	9.0	5.5	5.6
		24–36	C	3.4	6.8	8.4	25.8	19.1	26.2	8.9	5.5	1.4
4	Davidson	0–9	A	.7	2.3	2.6	9.6	16.7	29.4	34.3	25.9	4.4
		9–36	B_1	.1	.7	.9	5.4	8.9	22.3	60.4	54.0	1.3
		36–60	B_2	.3	1.0	.9	7.2	9.1	30.4	50.3	41.3	.3
		84–96	C	.4	1.3	1.9	14.3	17.5	34.5	29.6	23.7	.5
5	Nipe	0–12	1	4.6	4.1	2.0	2.3	1.6	21.2	63.9	50.2	.3
		40–60	2	3.0	6.1	3.8	6.1	4.0	16.3	61.1	56.3	.0
		100–144	3	4.0	4.2	2.1	2.3	1.3	21.7	64.0	50.4	.5
6	Bauxite, soft	156–214	4	19.3	15.9	6.6	8.5	5.0	25.5	17.8	11.8	1.5
	Kaolinized	250–290	6	.2	.7	.7	2.4	3.6	38.9	53.1	35.2	.3

[1] Determinations by L. T. Alexander and Hubert W. Lakin.

TABLE 2.—*Chemical composition of soils*[1]

Profile No.	Soil series	Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
		0–5	1	75.62	10.56	3.16	0.09	0.67	0.78	2.20
		10–20	2	70.48	13.88	4.40	.09	.97	1.35	2.56
1	Amarillo	30–40	3	68.72	13.25	4.31	.08	2.64	1.37	2.48
		54–64	4	74.49	11.67	3.83	.06	1.09	1.10	2.14
		70–75	5	40.42	6.69	2.04	.04	25.80	1.06	1.20
		96–100	6	56.71	.04	2.86	.06	14.11	1.22	1.71
		0–3	A_0	51.50	3.30	1.44	.08	1.29	.32	1.25
2	Superior	3–8	A_1	89.51	3.55	1.36	.01	.44	.13	2.15
		12–30	B	88.24	4.27	2.59	.01	.36	.40	1.61
		30–40	C	92.03	3.77	1.12	.01	.20	.23	1.39
		0–6	A_0	52.95	7.04	1.08	.01	.90	.15	2.06
		6–11	A_1	83.32	6.73	1.69	.01	.54	.18	2.89
3	Beckett	11–13	B_1	69.60	9.61	3.99	.01	.65	.33	3.41
		13–24	B_2	72.67	10.32	3.58	.02	.62	.41	3.45
		24–36	C	77.86	10.00	3.15	.03	.54	.48	3.79
		0–9	A	70.53	12.45	6.10	.22	.75	.45	.58
4	Davidson	9–36	B_1	52.70	22.87	10.62	.07	.51	.40	.45
		36–60	B_2	50.53	23.05	14.87	.08	.27	.58	.34
		60+	C	52.62	20.98	13.37	.47	.27	1.00	.72
		0–12	1	7.96	14.71	64.00	1.09	.41	.27	Trace.
5	Nipe	40–60	2	4.36	9.49	67.51	.44	.02	.27	.04
		100–144	3	11.03	15.23	55.22	.46	Trace.	.53	.12
6	Bauxite	156–214	4	4.45	55.14	6.28	.19	.04	.04	Trace.
		250–290	6	43.87	38.92	2.32	.26	.02	.02	.21

Profile No.	Soil series	Depth	Horizon	Na_2O	TiO_2	P_2O_5	SO_3	Ignition loss	N	pH
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
		0–5	1	1.06	0.78	0.10	0.07	4.98	0.13	6.5
		10–20	2	1.01	.71	.09	.07	4.94	.08	7.8
1	Amarillo	30–40	3	1.03	.74	.10	.06	5.50	.06	7.8
		54–64	4	.87	.95	.07	.21	3.82	.02	7.9
		70–75	5	.46	.42	.08	.13	21.82	.01	7.9
		96–100	6	.73	.57	.09	.11	13.00	.01	8.3
		0–3	A_0	.24	.25	.18	.33	39.77	1.17	4.7
2	Superior	3–8	A_1	.34	.34	.02	.07	1.68	.04	5.1
		12–30	B	.15	.19	.17	.05	1.94	.03	5.6
		30–40	C	.30	.10	.04	.03	.84	.01	5.6
		0–6	A_0	.40	.66	.13	.36	34.40	1.04	3.8
		6–11	A_1	.46	.90	.04	.13	2.75	.05	3.7
3	Beckett	11–13	B_1	.46	.79	.08	.20	11.25	.14	3.9
		13–24	B_2	.67	.70	.08	.14	7.27	.09	4.1
		24–36	C	.55	.53	.08	.13	2.54	.02	4.5
		0–9	A	.00	1.80	.10	.12	7.66	.11	6.3
4	Davidson	9–36	B_1	.00	1.39	.12	.12	10.55	.02	5.1
		36–60	B_2	.00	1.47	.20	.12	9.37	.01	4.4
		60+	C	.00	1.23	.24	.09	9.15	.01	4.1
		0–12	1	.03	.73	.04	.24	10.12	.08	5.4
5	Nipe	40–60	2	Trace.	.53	.01	.38	12.45	.00	5.9
		100–144	3	.15	.86	.05	.25	12.28	.12	5.4
6	Bauxite	156–214	4	.02	2.25	.14	1.29	30.48	.00	3.6
		250–290	6	.01	1.26	.03	.25	13.19	.00	3.0

[1] Determinations by G. H. Hough and G. E. Edgington.

Certain characteristic features of each group of soils are apparent from their mechanical and chemical compositions. In the case of pedocal soils that part of the profile which shows the presence of calcium carbonate gives a suggestion as to the general class to which the soil belongs. However, comparable quantities of calcium carbonate may be present in soils in the process of formation from calcareous parent material. In such cases lower pH values may usually be expected in the upper horizons than when the calcification process is in action in the profile.

In the case of profiles Nos. 2 and 3 the excessively high organic content of the A_o horizon (indicated from the nitrogen content and from the loss on treatment with hydrogen peroxide) compared with that of the lower horizons is immediately suggestive of the podsol class. To some extent the translocation of sesquioxides or organic matter or both from the A horizons to the B horizons are recognizable from the whole soil. This feature has been previously noted (*12*).

Typical laterites are the one group of soils easily recognizable by their chemical composition. The high content of sesquioxides, particularly at the surface, serves to characterize this group. In the case of lateritic or partly lateritized soils the chemical composition shows less marked evidence as to class.

Although the chemical composition of whole soils is to some extent diagnostic in indicating the general group to which a soil may belong, such interpretations from analyses are subject to sharp limitations. The character of the colloid is of particular significance, and variations in its composition may be much obscured by the varying mechanical composition of whole soil.

METHODS OF STUDY OF COLLOIDAL MATERIALS

Colloidal materials were extracted from each of the soils in a manner somewhat similar to that previously described (*13*). The separation of colloid was made by the use of a high-power centrifuge, 0.001 mm. being taken as the upper limit of particle size of the colloid. No attempt was made to extract all of the colloid present. However, each soil was extracted several times with large quantities of water, and the bulk of the easily dispersable colloid was separated. Several of the soil samples presented unusually difficult problems of dispersion. In cases where necessary a deflocculant was used. In most cases ammonium hydroxide was a satisfactory deflocculant. However, this did not produce dispersion of horizon No. 4 of profile No. 6. In this case long washing with water and subsequent treatment with sodium oxalate was found satisfactory. This treatment was necessary because of the presence of soluble aluminum sulphate and the high content of aluminum hydroxide.

Chemical analyses were made by the standard methods employed in this bureau for total constituents.

The heat of wetting was determined by the method described by Anderson (*4*). Determinations of this value for a few of the colloids which were exceedingly high in organic matter are not included, owing to the fact that they were only slightly wetted by water. Most of the powder floated on the surface even after vigorous stirring. The heat of wetting, of course, could have been determined in certain organic liquids, but it has been previously shown that no fixed relationship exists between heat of wetting of soil colloids by water and by alcohol or benzene (*5*).

The moisture-equivalent determination was carried out essentially according to the procedure described by Briggs and McLane (*9*) for soils.

The adsorption of water vapor was determined over 3.3 per cent sulphuric acid and over 30 per cent sulphuric acid (*29*, *7*). The two

sets of values have different significance. The adsorption value obtained for soil over 3.3 per cent acid is frequently used as a basis for determining approximate colloidal content, owing to the fact that the colloidal materials of most soils show little variation from an average of about 30 per cent adsorption of water over this strength of acid (*29*). These values, in addition to being presented in the tables, are also used as a basis of calculation of the approximate total quantity of colloid in the soil as outlined in this previous publication (*29*). Also in the process of mechanical analysis of soils, two values are obtained, the sum of which in most cases expresses the colloid with fair approximation. These are the mechanical fraction below 0.002 millimeter and the loss of weight by treatment with hydrogen peroxide. In the case of rather unusual horizons, such as are largely organic or highly lateritic, these methods give divergent results.

The contents of exchangeable monovalent and divalent bases were determined by treating the colloids with normal ammonium chloride solutions essentially according to the method of Kelley and Brown for soils (*21*). In the case of colloids containing calcium carbonates a procedure essentially as recommended by Magistad and Burgess (*24*) was used. This method employs ammonium chloride in 68 per cent alcohol instead of in water. In this procedure smaller quantities of calcium carbonate are dissolved than when water is used. In the present work no correction was made for the approximate solubility of calcium carbonate in salt solutions. The determination of exchangeable bases was omitted in a few cases where the contents of total bases shown by analysis were so small that probable error of the determinations would render the results of little significance.

Base-exchange capacity was determined essentially as described by Holmes (*17*), except that washing was done by means of Pasteur-Chamberland filters instead of on paper as it was found that some of the materials used in this study could not be properly washed on paper filters. Samples of about 4 grams each were treated with 100 cubic centimeters of normal barium chloride solution which had been adjusted to pH 7. After standing overnight the liquid was drawn off through the filters and washed with successive portions of barium chloride solution until the filtrate amounted to about 500 cubic centimeters. In order to remove the excess of barium chloride the samples were washed with water until free from chlorides. The barium held by the colloid was then extracted by means of 0.05 *N* HCl. In case of the colloids containing $CaCO_3$ the barium was removed by normal ammonium chloride instead of hydrochloric acid. In either case the barium in the filtrate was determined as sulphate.

The degree of saturation is calculated as a percentage of total capacity from the exchangeable monovalent and divalent bases, found by analysis, and the base capacity, shown by the barium chloride determination. It is recognized, of course, that this procedure, while standard, does not actually represent the replaceable bases and the hydrogen of the soil colloid but does to a marked degree make comparison of the varying colloids subjected to it.

For convenience the characteristics of the colloids of each soil group will be discussed separately.

CHARACTER OF PEDOCAL COLLOIDS

The characteristic process of pedocal formation consists in the conversion of calcium to the carbonate and its ultimate deposition in the form of the carbonate at varying depths below the surface. The influence of organic matter at the surface is assumed to be an important factor in this process. Carbon dioxide from organic decomposition aids in the solution of calcium as the bicarbonate. The low rainfall of these regions does not, as a rule, allow extensive percolation to great depths, and hence a deposit is formed, consisting essentially of calcium carbonate, at a position approximating the depths to which surface waters most frequently percolate. It is not necessary to assume, however, that all the calcium carbonate of the calcareous horizons came from the overlying strata. It is frequently assumed that materials may rise in the capillary water from lower strata and be precipitated in the zone of calcification. Previous studies have indicated that the colloids from surface soils of such regions tend to have relatively high silica-sesquioxide ratios.

The chemical composition of the colloids extracted from each horizon of a soil of this group, designated as profile No. 1, are given in Table 3. Properties of the same series of colloids are given in Table 4.

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TABLE 3.—*Chemical composition of pedocal soil colloids,*[1] *profile No. 1, Amarillo soil series*

Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	CO_2	Ignition loss	Organic [2] matter	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
0–5	1	50.51	22.04	8.80	0.14	1.48	2.08	2.68	0.06	0.56	0.20	0.18	None.	12.08	4.02	3.10
10–20	2	51.51	22.71	8.61	.09	1.59	2.66	2.54	.01	.57	.12	.14	None.	9.50	2.14	3.09
30–40	3	51.32	22.43	8.46	.05	2.27	2.80	2.50	.06	.58	.14	.14	.35	10.19	1.96	3.13
54–64	4	51.23	24.08	8.19	.07	1.73	2.83	2.42	.10	.55	.11	.13	None.	8.72	.96	2.97
70–75	5	38.42	17.64	5.71	.06	16.38	2.53	1.83	.06	.37	.09	.10	11.22	17.85	.42	3.06
96–100	6	45.88	20.09	6.89	.05	9.05	2.87	2.26	.01	.52	.11	.13	5.87	12.41	.13	3.18

[1] Chemical analyses by G. E. Edgington.

[2] Determined by combustion, $CO_2 \times 0.471$.

TABLE 4.—*Properties of pedocal soil colloids, profile No. 1, Amarillo soil series*

Depth	Horizon	Heat of wetting per gram of colloid	H_2O vapor adsorbed over 30 per cent H_2SO_4 per gram of colloid	H_2O vapor adsorbed over 3.3 per cent H_2SO_4 per gram of colloid	Moisture equivalent	Exchangeable bases per gram of colloid					Exchangeable base capacity per gram of colloid by $BaCl_2$	Degree of saturation	Colloid content of soil determined by H_2O adsorption	Colloid content by mechanical analysis	Colloid extracted from soil	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
						Ca	Mg	K	Na	Total						
Inches		*Calories*	*Gram*	*Gram*	*Per cent*	*Milliequivalents*	*Milliequivalents*	*Milliequivalents*	*Milliequivalents*	*Milliequivalents*	*Milliequivalents*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
0–5	1	16.8	0.154	0.300	84.3	0.389	0.159	0.034	0.006	0.588	0.566	[1]	25.7	25.9	18.2	3.10
10–20	2	18.5	.184	.340	85.0	.492	.149	.030	None.	.671	.628	[1]	39.1	43.9	10.5	3.09
30–40	3	18.0	.182	.334	85.6	.628	.154	.015	.019	.816	.634	[1]	35.9	38.1	13.8	3.13
54–64	4	19.5	.201	.363	88.5	.532	.149	.019	.026	.726	.692	[1]	30.3	34.9	10.0	2.97
70–75	5	13.8	.147	.292	78.9	1.027	.099	.017	None.	1.143	.656	[1]	24.1	36.1	10.5	3.06
96–100	6	18.0	.171	.331	86.6	.924	.099	.015	.009	1.047	.700	[1]	26.2	31.3	14.7	3.18

[1] Saturated.

Colloids developed in the Amarillo profile show uniformity of composition to a marked degree in all respects except in their content of calcium carbonate. This constancy of composition of major constituents throughout the profile is indicated by the small variation in silica-sesquioxide ratios, which range from 2.97 to 3.18. The unique feature of this class of profiles lies in the extent to which calcium carbonate is found in the colloids of the lower horizons.

Most of the property values for colloids of this profile are high, and their magnitudes are essentially of the order that should be expected from their silica-sesquioxide ratios. The only important deviation from regularity is in horizon 5, where the calcium carbonate content is about 25 per cent of the dry weights of the colloids. In this horizon the colloidal property values are lower than the mean for the profile by approximately the amount of calcium carbonate present, indicating that this material is essentially inert so far as such properties as heat of wetting and water adsorption are concerned. The inert character of colloidal calcium carbonate is in accordance with earlier observations in this bureau and elsewhere.[6]

CHARACTER OF PODSOL COLLOIDS

The podsolization process is usually regarded as essentially one of solution, true or colloidal, with subsequent transportation of the products of solution although other weathering alterations may also be taking place. This is in contrast to progressive weathering whereby partly decomposed residual products left in place predominate as is the case when calcification is in progress. Most of the dissolved materials are hydrolyzed, and the more soluble constituents pass into the drainage water, whereas the less soluble products are moved to lower horizons. It is a process involving movement of colloidal constituents, as well as more soluble nutrients, downward, leaving an impoverished upper layer. The mechanism of the action whereby the sesquioxides and organic matter move downward and are deposited in the B horizon is a matter which has been carefully investigated but not accounted for in an altogether satisfactory manner.

Data showing the accomplishment of the podsolization process as affecting the chemical compositions throughout the profile are given in Table 5, and properties of the same materials are given in Table 6.

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[6] McCool, M. M., and Wheeting, L. C. Op. cit.

TABLE 5.—*Chemical composition of podsol colloids* [1] *of Superior and Beckett soils*

Profile No.	Soil series	Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	Ignition loss	Organic [2] matter	Organic [3] matter	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
2	Superior	0–3	A_0	20.89	7.51	3.04	0.10	1.74	1.05	0.79	0.26	0.34	0.50	0.81	63.15	57.52	61.5	3.76
		3–8	A_1	46.20	16.67	4.55	.08	1.01	1.25	2.14	.34	.97	.39	.35	25.58	19.70	19.9	4.01
		12–30	B	31.60	25.14	13.47	.08	.66	1.71	1.37	.15	.88	.96	.18	23.35	9.96	9.6	1.59
		30–40	C	42.20	22.02	12.31	.12	.61	3.41	1.23	.06	1.57	.31	.17	15.59	5.35	5.9	2.40
3	Beckett	0–6	A_0	10.58	5.99	3.64	.02	.65	.31	.49	.25	.49	.31	.99	75.87	69.98	68.1	2.16
		6–11	A_1	38.39	20.26	5.55	.02	.40	1.03	2.51	.24	1.48	.25	.23	29.25	26.78	22.2	2.74
		11–13	B_1	13.40	12.02	22.38	.10	.32	.65	.83	.12	.90	.60	.44	47.90	39.05	40.4	.86
		13–24	B_2	21.56	20.06	13.02	.06	.16	1.18	1.98	.28	.74	.37	.35	39.78	30.34	32.3	1.28
		24–36	C	34.31	27.55	11.60	.01	.17	2.10	4.10	.25	.72	.18	.19	18.82	9.48	9.6	1.67

[1] Chemical analyses by G. E. Edgington. [2] Determined by combustion, $CO_2 \times 0.471$. [3] Determined by loss on treatment with H_2O_2.

TABLE 6.—*Properties of podsol colloids of Superior and Beckett soils*

Profile No.	Soil series	Depth	Horizon	Heat of wetting per gram of colloid	H_2O vapor adsorbed over 30 per cent H_2SO_4 per gram of colloid	H_2O vapor adsorbed over 3.3 per cent H_2SO_4 per gram of colloid	Moisture equivalent	Exchangeable bases per gram of colloid					Exchangeable base capacity per gram of colloid by $BaCl_2$	Degree of saturation	Colloid content of soil determined by H_2O adsorption	Colloid content of soil by mechanical analysis	Colloid extracted from soil	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
								Ca	Mg	K	Na	Total						
		Inches		*Calories*	*Gram*	*Gram*	*Per cent*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
2	Superior	0–3	A_0	----------	0.137	0.410	112.0	0.414	0.124	0.036	0.055	0.629	0.781	80.5	51.1	42.1	1.7	3.76
		3–8	A_1	11.1	.083	.211	86.5	.321	.084	.032	.061	.498	.563	88.5	4.4	2.9	.4	4.01
		12–30	B	16.3	.159	.386	68.1	.200	.064	.013	.003	.280	.440	63.6	6.6	6.1	3.0	1.59
		30–40	C	9.7	.083	.258	70.9	.164	.104	.028	None.	.296	.399	74.2	2.1	2.8	.9	2.40
3	Beckett	0–6	A_0	----------	.162	.350	93.0	.117	.074	.015	.045	.251	.789	31.8	42.3	32.2	2.2	2.16
		6–11	A_1	8.0	.080	.188	91.4	.095	.040	.011	.019	.165	.511	32.3	8.7	5.9	1.5	2.74
		11–13	B_1	----------	.129	.247	----------	----------	----------	----------	----------	----------	----------	----------	33.4	14.9	1.7	.86
		13–24	B_2	8.9	.147	.265	90.8	.061	.025	.008	.026	.120	.537	22.3	16.8	11.1	1.0	1.28
		24–36	C	10.5	.092	.248	83.6	.045	.015	.006	None.	.066	.189	34.9	8.2	6.9	1.5	1.67

Various phases of the process whereby podsolization takes place have been carefully studied by several European investigators. There appears, however, to be still some difference of opinion as to the part played by eluviation and that by solution and subsequent precipitation in the transportation of colloidal materials in a podsol profile. There appears to be little doubt that both processes are operative. Tamm (*31*) believes the transportation of colloidal material in a dispersed condition to be of particular importance. He interprets the process of ortstein formation to be the result of the flocculation by humus of silicic acid, alumina, and iron oxide, which have been transported in the soil as colloidal matter. Albert (*3*) and Aarnio (*1*) have made careful studies of the relation of organic matter to the solution and precipitation of alumina and iron as ions and as colloidal solutions. Albert (*3*)[7] found about the same oxidizing conditions in the A and in the B horizons. From these experiments there appears to be little reason for assuming the solution of ferrous organic compounds in the A horizon and their subsequent precipitation in the B horizon as ferric compounds. From this work the presumption is that the movement is largely mechanical. The work of Aarnio (*1*) emphasizes the importance of the proportions of organic matter in colloids of iron and alumina as determining whether a dispersion or precipitate will result. The present investigation does not presume to answer the question of the nature of the movement of this soil material, nevertheless certain data presented in Table 5 have a bearing on this question and are of interest for brief consideration.

There is abundant evidence in many soils, particularly those of the coastal-plain region which are podsolic in character but not true podsols, that colloidal material may be transported downward mechanically and either filtered out or flocculated in lower horizons. Evidence in support of this explanation lies in the approximate uniformity of character of the colloids in the A and B horizons of such soils, but such evidence is lacking in the true podsols, for there the colloids of the A_1 and the adjoining B horizons show wide differences in chemical composition. Thus it is evident that the colloid has not moved downward in unchanged composition from the A to the B horizons in such cases. Not only is there a marked difference in the ratios of the silica to sesquioxides of the two horizons, but the iron and alumina appear in widely differing proportions as well.

It will be noted in Table 10 (p. 20) that when calculations are made on the basis $SiO_2+Al_2O_3+Fe_2O_3=100$, there is only a moderate variation in alumina in the B horizons as compared with the A_1 horizons, whereas the increase in iron in the B horizons of the corresponding profiles is enormous. Calculations from these figures show, in the case of the Beckett profile, about 20 per cent less alumina in the colloid of the B horizon than in the A_1 horizon. The iron increase, however, amounts to about 442 per cent. The Superior profile shows a similar contrast although somewhat less marked. The laboratory studies of Aarnio (*1*) indicate that relatively much larger quantities of organic matter are required to precipitate alumina sols than are

[7] True podsols as understood in this bulletin are developed only under good drainage and free from the influence of ground water.

required for equivalent concentrations of iron preparations. The variation in the precipitation of the two sesquioxides on the basis of these experiments would seem to account for the general character of the differences between the colloids of the A and of the B horizons. There are, doubtless, other factors involved, which further data would help to clarify. For instance, the influence of iron and aluminum ions in a solution as acid as pH 4 is not to be disregarded. Moreover, the reason for extensive colloidal dispersion in a medium as acid as this is not altogether clear.

Property values for colloids of the two podsol profiles show characteristics as variable as those of chemical composition. Each profile shows relatively high values for the colloid of the A_0 horizon, much lower values for the A_1 horizon, and the B values are considerably higher than those of the A_1. The colloid property values throughout the podsol profiles show very different relationships to the major constituents from those ordinarily found. For instance, the A_1 horizons show the highest ratio of silica to sesquioxides, but the property values are low. The colloids of the B horizons have low silica-sesquioxide ratios, but the property values are much higher than those ordinarily associated with this feature of chemical composition. One factor which should be considered in this connection is that the A_1 horizons of both of these soils are of relatively coarse texture and consist chiefly of very fine quartz particles and fragments of organic matter (Table 1), the easily extractable portion of the colloid being very small. Under these circumstances it would not be surprising if appreciable quantities of quartz particles below the limit of 0.001 millimeter in size were not included in the colloid.

Examination of the optical properties of these two colloids by Hendricks and Fry of this bureau (*15*) showed in each case that no quartz was detectable with the petrographic microscope, but X-ray examination showed its presence to the extent of at least 10 per cent. This might account to some extent for the anomalous properties of these colloids, for it has been shown that some of the properties of colloidal quartz have very small values (*4*, *6*). This is in accord with the somewhat abnormal behavior of the Leonardtown silt loam as reported by Holmes (*17*).

The high and varying organic content of the colloids of the podsol profiles and the anomalous behavior of these colloids with regard to their major inorganic constituents suggests that organic matter may have an important influence on certain properties. In several cases indirect evidence has shown soil organic matter to be relatively high in base-exchange capacity (*16*, *22*). This does not seem to be true in all cases, however, for Burgess and McGeorge (*10*) found negligible base-exchange capacity in an organic preparation from an alkali soil.

In view of the high organic content of some of the podsol colloids it was thought desirable to remove the organic matter by hydrogen peroxide and to redetermine certain properties. The complete removal of organic matter from some of these colloids was very difficult, and even its incomplete removal from a sample of any considerable size required enormous quantities of hydrogen peroxide, with frequent removal of the soluble products by washing. In each

case the soluble constituents were finally removed through a Pasteur filter and the residue washed several times with water.

A comparison of the properties of colloids containing large quantities of organic matter and the same colloids after most of the organic matter had been removed by hydrogen peroxide is given in Table 7. Included in this table also is a sample of organic matter prepared from horizon B_2 of the Beckett profile by treatment with strong ammonia and subsequent precipitation with acid.

The removal of organic matter greatly reduced all the property values studied. Calculation of the part contributed by the organic matter to each of the properties shows its influence to be of relatively high magnitude. The data in Table 7 indicates some variability in the organic colloid of the different samples and also some variation in the influence of a particular colloid on different properties. In each case the organic colloid showed higher colloidal properties than the inorganic portion.

TABLE 7.—*Effect of hydrogen peroxide treatment on the properties of soil colloids of Superior and Beckett soils*

Soil series	Depth	Horizon	Treatment	Organic matter content[1]	Base-exchange capacity per gram of colloid by $BaCl_2$	Adsorption of H_2O over 30 per cent H_2SO_4 per gram of colloid	Heat of wetting per gram of colloid	Calculated base-exchange capacity per gram of organic colloid	Calculated adsorption of H_2O per gram of organic colloid	Calculated heat of wetting per gram of organic colloid
	Inches			*Per cent*	*Milli-equivalents*	*Gram*	*Calories*	*Milli-equivalents*	*Gram*	*Calories*
Beckett	0–6	A_0	None.	68	0.789	0.162	(2)	1.052	0.231	
	0–6	A_0	H_2O_2	12	.329	.042	(2)			
	6–11	A_1	None.	22	.511	.080	8.0	1.024	.157	19.1
	6–11	A_1	H_2O_2	3	.386	.047	5.3			
Superior	0–3	A_0	None.	62	.781	.137	(2)	1.080	.177	
	0–3	A_0	H_2O_2	8	.356	.080	(2)			
	3–8	A_1	None.	20	.563	.083	11.1	1.103	.135	26.7
	3–8	A_1	H_2O_2	2	.371	.061	6.2			
Superior	12–30	B	None.	10	.440	.159	16.3	2.195	.330	46.9
	12–30	B	H_2O_2	None.	.245	.140	12.9			
Organic matter from Superior B soil.					1.237					

[1] The approximate organic contents of the H_2O_2 treated samples were computed from the differences between their loss on ignition and the ignition loss of small samples repeatedly treated with H_2O_2 and subsequently washed.

[2] Partly wetted by water.

Although organic matter in the different horizons shows considerable variation in its influence on certain properties, the data in Table 5 indicate fairly close similarity in ultimate composition. This is indicated by the fairly close agreement between the organic content calculated from the carbon dioxide given off on combustion and the organic content indicated by loss on treatment with hydrogen peroxide. No exact correspondence between these values is to be expected because of the uncertainties involved in the use of the Van Bemmelen factor in the combustion method and the probable occurrence of base-exchange phenomena due to both the preservative used in hydrogen peroxide and the ammonia formed in the process.

CHARACTER OF LATERITE AND LATERITIC COLLOIDS

The first stage of the lateritization process is generally assumed to be one of kaolinization. Silicate minerals would, it is assumed, form alkaline solutions by hydrolysis and, under these conditions, a kaolinized product be formed. Under conditions of high temperature and abundant moisture the kaolin is converted by further hydrolysis and the removal of silica to hydrated oxides of aluminum and iron with the simultaneous removal of more soluble silica. Lateritization is therefore signalized by a lowering of the silica-sesquioxide ratio and a high degree of unsaturation of exchange bases. Indeed, as indicated by Martin and Doyne (*26*), the lateritization may at times keep pace with the kaolinization.

True laterite soils, with their exceedingly high sesquioxide contents, are so distinctive that they are usually distinguishable by a chemical analysis of either the whole soil or colloid. If the whole profile, horizons of which may contain kaolinitic material, be considered, the composition of individual horizons alone might not readily identify this soil group.

The influence of the lateritization process on the character of soil colloids is shown by a study of the colloids from soils of profiles Nos. 4, 5, and 6. The chemical analyses are given in Table 8 and the properties in Table 9. The chemical analyses of the whole soils are also shown in Table 2.

The Davidson profile, No. 4, shows the lateritic process in progress. Sesquioxides are relatively high in proportion to silica but have not yet reached the extreme proportions characteristic of true laterites. The chemical constituents show a high degree of constancy throughout the profile, and property values are of about the magnitude usually found in colloids with similar silica-sesquioxide ratios.

The Nipe profile, No. 5, represents a highly developed ferruginous laterite. The colloid of the first horizon has been previously studied, and most of the data for this horizon given in Tables 8 and 9 are taken from a recent publication (*5*). The Nipe soil shows the very effective removal of silica by the lateritization process throughout the profile. It will be noted in the case of both this profile and the highly aluminous horizon of profile No. 6 that the colloidal materials show somewhat higher percentages of silica than do the whole soils. This relationship is in contrast to that of most soils, for as a rule colloids are distinctly lower in silica than the soils from which they are extracted. This relationship in the case of laterites is not surprising, since the hydrated oxides of iron and aluminum are usually not easily dispersed and the presence of some silica forms a complex which is often more easily dispersable. Indeed, it is probable that the silica found in the colloid represents the residuum of unhydrolyzed clay.

The silica-sesquioxide ratios of the Nipe colloids are very low, much lower than those of the Davidson. Property values are also low, but such properties as adsorption and heat of wetting are not appreciably different from those of the Davidson colloids, indicating that there is some evidence that minimum values for certain properties may be reached before silica-sesquioxide ratios approach the zero value.

TABLE 8.—*Chemical composition of laterite colloids*[1] *of Davidson and Nipe soils and bauxite*

Profile No.	Soil series	Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	Ignition loss	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
4	Davidson	0–9	A	34.43	32.10	12.40	0.24	0.58	0.92	0.50	0.03	0.99	0.25	0.17	17.08	1.46
		9–36	B_1	36.92	31.67	16.03	.06	.56	.41	.37	None.	.92	.18	.12	13.14	1.49
		36–60	B_2	35.37	29.44	20.61	.08	.35	.36	.18	Trace.	.98	.17	.11	12.30	1.42
		60+	C	35.24	29.69	20.10	.30	.50	.06	.17	Trace.	.95	.36	.14	12.53	1.40
5	Nipe	0–12	1	10.19	15.84	62.51	-------	.23	.05	(2)	Trace.	-------	-------	-------	9.86	.31
		40–60	2	5.55	11.47	66.59	.36	(2)	.07	.07	.02	.41	.03	.14	13.51	.17
		100–144	3	12.89	17.93	53.52	.58	(2)	.21	.16	.03	.57	.05	.14	12.70	.42
6	Bauxite	156–214	4	23.83	43.29	7.56	.35	(2)	.09	.02	.08	4.44	.23	.15	19.70	.84
		250–290	6	44.02	39.42	1.83	.10	(2)	.06	.05	(2)	.37	.03	.05	13.93	1.84

[1] Analyses by G. E. Edgington.

TABLE 9.—*Properties of laterite and lateritic colloids of Davidson and Nipe soils and bauxite*

Profile No.	Soil series	Depth	Horizon	Heat of wetting per gram of colloid	H_2O vapor adsorbed over 30 per cent H_2SO_4 per gram of colloid	H_2O vapor adsorbed over 3.3 per cent H_2SO_4 per gram of colloid	Moisture equivalent	Exchangeable bases per gram of colloid					Exchangeable base capacity per gram of colloid by $BaCl_2$	Degree of saturation	Colloid content of soil determined by H_2O adsorption	Colloid content of soil by mechanical analysis	Colloid extracted from soil	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
								Ca	Mg	K	Na	Total						
		Inches		*Calories*	*Gram*	*Gram*	*Per cent*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
4	Davidson	0–9	A	7.5	0.045	0.209	67.1	0.064	0.025	0.004	0.010	0.103	0.183	56.3	27.3	30.3	19.0	1.46
		9–36	B_1	5.8	.055	.295	78.8	.032	.020	.002	.008	.062	.126	49.2	64.8	55.3	55.7	1.49
		36–60	B_2	6.0	.058	.319	79.7	.023	.020	.002	.010	.055	.158	34.8	66.5	41.6	42.0	1.42
		84–96	C	6.3	.058	.315	79.4	.025	.020	.004	.026	.075	.156	48.1	29.6	24.2	22.1	1.40
5	Nipe	0–12	1	6.4	.054	.241	58.0	-------	-------	-------	-------	-------	.031	-------	73.9	50.5	-------	.31
		40–60	2	6.8	.053	.240	-------	-------	-------	-------	-------	-------	.020	-------	92.6	56.3	8.1	.17
		100–144	3	5.8	.057	.256	48.8	-------	-------	-------	-------	-------	.021	-------	117.6	50.9	10.0	.42
6	Bauxite	156–214	4	2.9	.018	.065	52.6	-------	-------	-------	-------	-------	.087	-------	32.8	13.3	-------	.84
		250–290	6	1.8	.009	.057	58.1	-------	-------	-------	-------	-------	.199	-------	57.4	35.5	22.0	1.84

The two horizons of the bauxite profile present marked contrasts in the composition of their colloids. The composition of the highly aluminous layer shows a high sesquioxide content characteristic of the laterites, whereas the kaolinitic layer varies but little from the theoretical value of the silica-sesquioxide ratio for kaolinite. Incidentally it may be mentioned that the loss on ignition, in this case practically wholly water, is almost exactly the theoretical value for kaolinite. Property values for the colloids of both horizons are very low, the properties of the kaolinitic layer being far below those usually accompanying soil colloids of corresponding silica-sesquioxide ratio, and more like those of certain pure mineral colloids (*4*, *6*, *27*).

In view of the unusual character of the colloids of these two horizons it was thought that data regarding their optical properties would be of interest. According to an examination of these two colloids made by W. H. Fry of this bureau, by means of a petrographic microscope, the great mass of the material from the kaolinized horizon is isotropic and has colloidal characteristics. In this isotropic mass faint points of light, between crossed nicols, are plentiful and suggest extremely small crystals. The refractive index of the isotropic aggregates is about 1.56. Occasional faintly doubly refracting aggregates were found. These had an index the same as the isotropic material. Only vague shadows could be observed as interference figures, and these were indeterminate. Very rare crystals, too small for complete study, show the refractive index and approximately the interference figure and axial angle of kaolinite. The material of the aluminous horizon is well aggregated, the aggregates showing a brownish coloration in transmitted light. Practically all the aggregates show a faint double refraction between crossed nicols; but not even a suggestion of an interference figure was obtained. The refractive index is difficult to measure on account of the coloration of the aggregates but is approximately 1.58.

In several respects these materials differ significantly in optical characteristics from those of a large group of colloids described by Hendricks and Fry (*15*). The aluminous horizon was characterized by the absence of any suggestion of an interference figure and by the deep coloration of the colloidal aggregates. The colloid from the kaolinized material was even more strikingly different from that of the commonly obtained soil colloids. It was isotropic, whereas practically all the others studied were anisotropic. It had a lower index of refraction than any of the soil colloids previously reported and lacked the mass optical effect which is usually found.

The exchangeable bases present in the colloids from profiles Nos. 5 and 6 were not determined, since it was shown that the content of total monovalent and divalent bases given in Table 8 are very small and in several cases not more than a trace. The exchangeable base capacity is very small, and judging from the pH values of the soils given in Table 2, the presumption is that the degree of saturation is relatively low. The horizons of profile No. 6, particularly of horizon No. 4, contain a little soluble aluminum sulphate, which is sufficient to account for its low pH value and its high SO_3 content.

COMPARISON OF COLLOIDS FROM DIFFERENT SOIL GROUPS

The reactions typical of the different soil-making processes take place under widely differing climatic conditions and are distinctive in character. However, the different processes may result in the formation of profiles having horizons whose colloids possess considerable similarity in chemical character.

In order to facilitate comparison of the colloids of the different classes their major constituents have been recalculated on the basis $SiO_2+Al_2O_3+Fe_2O_3=100$. These values, together with the silica-sesquioxide ratios from previous tables, are given in Table 10.

TABLE 10.—*Chemical composition of soil colloids calculated on the basis* $SiO_2+Al_2O_3+Fe_2O_3=100$

Profile No.	Soil series	Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	Mols $\frac{SiO_2}{Al_2O_3\ Fe_2O_3}$
		Inches		*Per cent*	*Per cent*	*Per cent*	
1	Amarillo	0–5	1	62.09	27.09	10.82	3.10
		10–20	2	62.19	27.42	10.39	3.09
		30–40	3	62.43	27.28	10.29	3.13
		54–64	4	61.35	28.84	9.81	2.97
		70–75	5	62.20	28.56	9.24	3.06
		96–100	6	62.97	27.57	9.46	3.18
2	Superior	0–3	A_0	66.44	23.89	9.67	3.76
		3–8	A_1	68.52	24.72	6.75	4.01
		12–30	B	45.01	35.81	19.18	1.59
		30–40	C	55.14	28.77	16.09	2.40
3	Beckett	0–6	A_0	52.35	29.64	18.01	2.16
		6–11	A_1	59.80	31.56	8.64	2.74
		11–13	B_1	28.03	25.15	46.82	.86
		13–24	B_2	39.46	36.71	23.83	1.28
		24–36	C	46.71	37.50	15.79	1.67
4	Davidson	0–9	A	43.62	40.67	15.71	1.46
		9–36	B_1	43.63	37.43	18.94	1.49
		36–60	B_2	41.41	34.46	24.13	1.42
		60+	C	41.44	34.92	23.64	1.40
5	Nipe	0–12	1	11.51	17.89	70.60	.31
		40–60	2	6.64	13.72	79.64	.17
		100–144	3	15.28	21.26	63.46	.42
6	Bauxite	156–214	4	31.91	57.97	10.12	.84
		250–290	6	51.62	46.23	2.15	1.84

So far as the major constituents alone are concerned the podsol colloids embody in a single profile a range of chemical variation comparable with the colloids from the widest extremes of climate. In the A_1 horizons they are as high in silica and have as high silica-sesquioxide ratios as colloids from pedocal profiles formed under low rainfall. In the B horizons they have the silica-sesquioxide relationships characteristic of hot humid conditions where lateritization is far advanced. The profiles as a whole, however, show wide differences from those of either the pedocal or lateritic soils. Under these circumstances variations in some of the minor constituents, such as organic matter and monovalent and divalent bases, indicate significant differences between the groups. Furthermore, there is some evidence that even the iron present may show differences not revealed by a gross analysis of major constituents. Qualitative observations indicate a marked difference in the character of the iron compounds of the B horizons of the podsols as compared with either the laterites or the red colloids of the pedocal profile, the iron in the podsols being much more soluble in 0.05 *N* HCl. The podsol colloids of the B horizons have monovalent and divalent bases somewhat in excess

of those of lateritic colloids of similar major constituents. Furthermore, the podsol colloids of the A horizons with major constituents similar to those of the pedocals have somewhat similar base contents but are characterized by property values much lower than those of colloids from the more arid regions. This is probably to be accounted for by the presence of free silica in the colloid.

The data given in Tables 6 and 9 show, in some cases, much wider variations in the adsorption of water vapor over 3.3 per cent sulphuric acid than the values shown for the colloids of most agricultural soils. There are some indications that in certain of these unusual soils, samples of the colloid extracted may be less representative of the whole amount present and that greater alteration of adsorptive power may take place on extraction than is usually the case (*13*). This determination when used as a basis for estimating the colloid content of soils would then in these unusual cases, whether of large organic content or of very low silica-sesquioxide ratio, be expected to show somewhat less accurate results than are usually obtained by this method. Therefore, the results in Tables 4, 6, and 9, comparing the colloid contents by two methods, show in some cases discrepancies of the type that would be expected. These discrepancies would, of course, be in some cases, minimized and in others increased if an arbitrary adsorption value of 30 per cent were assumed for the colloid in each case.

Values for colloid content indicated by the other methods dependent on property values of the colloids would also be expected to show less than the ordinary degree of accuracy.

pH VALUES OF ELECTRODIALYZED COLLOIDS

The pH values of the different isolated colloids are not included in the data presented in the foregoing tables on account of the influence which varying quantities of deflocculant may have had on this determination. There is, however, some indication that the pH values of the colloids after electrodialysis may be of significance.

It is well known that electrodialyzed soils are usually much more acid than the most extreme samples of naturally occurring agricultural soils. There is also an indication that the pH values of different electrodialyzed soils may show considerable variation (*2*, *8*, *19*). It may be assumed that the acid character of the electrodialyzed soils resides primarily in the colloidal material and that the intensity of the acidity developed may, like many other properties, vary with the chemical character of the colloids.

Preliminary study of a few of the colloids used in the present investigation showed significant differences in the pH values of certain ones having varying silica-sesquioxide ratios. It seemed desirable therefore to investigate the remainder of the group. As the work progressed it became evident that the determination was greatly influenced by several factors, important among which are the colloid-water ratio and presumably the state of dispersion, although no specific data were obtained regarding the magnitude of the latter. Duplicate results of pH determinations may be obtained readily when samples of a colloid in a similar physical condition are electrodialyzed and the same proportions of colloid and water used. But if the condition of the material varies, there is indication that considerable

differences in pH values may be expected. Each of the colloids dialyzed in these studies had been air-dried and ground previous to dialysis. As the work progressed it appeared probable that somewhat lower pH values might, in some cases at least, have been obtained if freshly dispersed colloid had been placed in the dialyzer instead of that which had been air-dried. Colloids of course flocculated in the dialyzer and settled, leaving ordinarily a clear supernatant liquid. It was possible to obtain from the bottom of the chamber any concentration of suspension desired. An attempt was made in each case to use for pH determinations approximately the maximum concentration in which an electrometric determination could be properly made in an electrode vessel of the bubbling type. The ratio of colloid to water was in most cases approximately 1 to 2 or 3.

The pH values of the various electrodialyzed colloids are given in Table 11. Included in this table are the pH values of the freshly dialyzed colloid, the same colloids after being air-dried for several weeks and subsequently submerged in water for three days, also the pH values of the supernatant liquid from the colloid in the dialyzer when it was obtainable clear or nearly so.

The data in Table 11 indicate a tendency toward a direct relationship between hydrogen-ion concentration and silica-sesquioxide ratio. This relationship is, however, not a close one, and about all that can be said from the data at hand is that the hydrogen-saturated laterites have, as a rule, higher pH values than those of colloids of higher silica-sesquioxide ratio. If methods were available which would obviate the variations due to differences in dispersion and other more or less intangible factors, the relationship might appear much closer. As a rule, the colloids of low silica-sesquioxide ratio show a more marked tendency toward flocculation when hydrogen saturated than do those of higher ratio, and this may be responsible for part of the differences in pH value.

TABLE 11.—*Hydrogen-ion concentration of electrodialyzed soil colloids*

Soil series	Horizon	Depth	Minimum pH of fresh suspension	pH after drying and 3 days' subsequent submersion	pH of clear liquid above colloid	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches				
Amarillo	1	0–5	3.18	3.24	6.87	3.10
	2	10–20	2.88	3.44	4.95	3.09
	3	30–40	3.01	3.31	6.58	3.13
	4	54–64	2.45	3.29		2.97
	5	70–75	3.08	3.75		3.06
	6	96–100	3.08	3.56	6.89	3.18
Superior	A_0	0–3	2.73		4.73	3.76
	A_1	3–8	3.21			4.01
	B	12–30	4.24		5.91	1.59
	C	30–40	4.15	4.78	5.81	2.40
Beckett	A_0	0–6	3.02		6.24	2.16
	A_1	6–11	2.15	3.04	4.60	.86
	B_2	13–24		4.78		1.28
Davidson	A	0–9	3.06	4.85		1.46
	B_1	9–36	3.31	3.58		1.49
	B_2	36–60	3.97	4.02		1.42
	C	60+		4.21		1.40
Nipe	1	0–12	5.08		5.12	.31
	3	100–144	5.27		6.07	.42
Bauxite	4	156–214	4.36		6.45	.84
Kaolinized syenite	6	250–290	4.29			1.84

Marked differences have been observed by Bradfield (*8*) in the pH values of electrodialyzed colloids and clear solutions from which the colloidal materials have settled. It is evident that the hydrogen ions closely associated with the micellæ are in many cases responsible for most of the acidity shown by such materials. Taking the colloid from horizon 1 of the Amarillo profile as an illustration, the supernatant liquid shows only negligible deviation from theoretical neutrality, whereas a suspension of the colloid shows a pH value corresponding to about 0.0007 normal solution of completely ionized acid. In view of the enormous influence of what may be presumed to be surface hydrogen ions it may be assumed that surface contact of a colloid micella upon the hydrogen electrode is an important factor in the pH determination of such materials.

The colloids which were air-dried and remained in this condition for several weeks before being submerged and the pH values redetermined, show in most cases, higher pH values than the fresh materials. Although a part of the apparent comeback may have been due to poorer dispersion after drying, nevertheless, some real change probably took place. The work of Alben (*2*) with soils showed about the same differences in pH value when electrodialyzed soils were kept submerged and when allowed to dry out. The comeback shown by the electrodialyzed colloids is probably indicative of a tendency on the part of the so-called nonexchangeable bases to undergo rearrangement within the particle in such manner that a part of such bases are capable of ionizing in the surface layer. In other words, this change is indicative of a transformation of some of the nonexchangeable base into exchangeable form. This explanation accords with unpublished data presented by Kelley (*20*).

SUMMARY

The results of the influence of each of three major soil-making processes on the character of the colloidal materials developed in a soil profile were studied. The processes include calcification, podsolization, and lateritization. Each profile studied is representative of the dominating influence of a single one of these processes operative to the extent of developing a typical profile of its kind.

The chemical composition of each of the colloids and the various properties which serve to characterize these materials were studied. These properties include heat of wetting, adsorption of water vapor over 30 per cent sulphuric acid and over 3.3 per cent sulphuric acid, moisture equivalent, content of exchangeable monovalent and divalent bases, and base-exchange capacity.

On the basis of the data presented the calcification process leads to uniformity of colloidal material so far as major chemical constituents are concerned. The ratio of silica to sesquioxides is relatively high as are also most of the property values. Colloidal calcium carbonate is present in the lower horizons and this material appears to possess relatively low property values.

The podsolization process leads to the formation of profiles containing colloidal materials of widely varying character in the different horizons. Silica-sesquioxide ratios of the A_0 and A_1 horizons are high, those of the B horizons are relatively low, and those of the C somewhat higher than those of the B. Property values of the A_1

and B colloids are anomalous, those of the A_1 being much lower and those of the B horizon colloids much higher than usually accompany such silica-sesquioxide ratios. Organic matter is shown to play an important part in the properties of these colloids.

The lateritization process leads to the development of colloids whose ratio of silica to sesquioxides is low and whose property values are low. The kaolinized horizon has low property values comparable to those of mineral powders rather than to ordinary soil material.

The hydrogen-ion concentration of electrodialyzed colloids varies widely. These variations show no close relationship to chemical composition. However, there is some tendency toward a direct relationship between hydrogen-ion and silica-sesquioxide ratio, the pH values of the laterites being much higher than those of colloids with high silica-sesquioxide ratio. Long standing of the colloids after electrodialysis brought about an increase in pH values, suggesting that a part of the nonexchangeable bases of the colloid particles may have become exchangeable, thus replacing some of the hydrogen-ions in the surface layers.

LITERATURE CITED

(1) Aarnio, B.
1915. Über die ausfällung des eisenoxydes und der tonerde in finnländischen sand- und grusböden. Finland Geol. Komm. Geotek. Meddel 16, 76 p., illus.

(2) Alben, A. O.
1930. Reactions of electrodialyzed humus and bentonite and application of the method. Jour. Amer. Soc. Agron. 22: 311–326, illus.

(3) Albert, R.
1910. Beitrag zur kenntnis der ortsteinsbildung. Ztschr. Forst u. Jagdw. 42; 327–341.

(4) Anderson, M. S.
1924. The heat of wetting of soil colloids. Jour. Agr. Research 28: 927–935.

(5) ———
1929. The influence of substituted cations on the properties of soil colloids. Jour. Agr. Research 38: 565–584.

(6) ——— Fry, W. H., Gile, P. L., Middleton, H. E., and Robinson, W. O.
1922. Absorption by colloidal and noncolloidal soil constituents. U. S. Dept. Agr. Bul. 1122, 20 p.

(7) ——— and Mattson, S.
1926. Properties of the colloidal soil material. U. S. Dept. Agr. Bul. 1452, 47 p., illus.

(8) Bradfield, R.
1928. The use of electrodialysis in physico-chemical investigations of soils. First Internatl. Cong. Soil. Sci. Proc. and Papers 1927, Comm. II: 264–278.

(9) Briggs, L. J., and McLane, J. W.
1907. The moisture equivalents of soils. U. S. Dept. Agr., Bur. Soils Bul. 45, 23 p., illus.

(10) Burgess, P. S., and McGeorge, W. T.
1927. Zeolite formation and base-exchange reactions in soils. Ariz. Agr. Expt. Sta. Tech. Bul. 15, p. 359–399, illus.

(11) Denison, I. A.
1930. The chemical composition of colloidal material isolated from the horizons of various soil profiles. Jour. Agr. Research 40: 469–483.

(12) Edgington, G., and Adams, J. R.
1925. Distribution of nitrogen in the podsol profile. Soil Sci. 20: 177–179.

(13) GILE, P. L., MIDDLETON, H. E., ROBINSON, W. O., FRY, W. H., and ANDERSON, M. S.
1924. ESTIMATION OF COLLOIDAL MATERIAL IN SOILS BY ADSORPTION. U. S. Dept. Agr. Bul. 1193, 42 p.
(14) HARRASSOWITZ, H.
1926. LATERIT, MATERIAL UND VERSUCH ERGESCHICHTLICHER AUSWERTUNG. Fortschr. Geol. u. Paläontol. Bd. 4, Heft 14, p. 253–566.
(15) HENDRICKS, S. B., and FRY, W. H.
1930. THE RESULTS OF X-RAY AND MICROSCOPICAL EXAMINATIONS OF SOIL COLLOIDS. Soil Sci. 29: 457–479, illus.
(16) HISSINK, D. J.
1925. BASE EXCHANGE IN SOILS. Faraday Soc. Trans. 20: 551–569, illus.
(17) HOLMES, R. S.
1928. VARIATIONS OF THE COLLOIDAL MATERIAL IN TYPICAL AREAS OF THE LEONARDTOWN SILT LOAM SOIL. Jour. Agr. Research 36: 459–470.
(18) ——— and EDGINGTON, G.
1930. VARIATIONS OF THE COLLOIDAL MATERIAL EXTRACTED FROM THE SOILS OF THE MIAMI, CHESTER, AND CECIL SERIES. U. S. Dept. Agr. Tech. Bul. 229, 24 p., illus.
(19) HUMFELD, H., and ALBEN, A. O.
1927. ELECTRODIALYSIS OF SOILS: I. A STUDY OF THE METHOD. Jour. Amer. Soc. Agron. 19: 984–993, illus.
(20) KELLEY, W. P.
1929. THE NATURE OF THE BASE EXCHANGE MATERIAL OF SOILS. [A paper read at the annual meeting Amer. Soc. Agron. and awaiting publication in Soil Sci.]
(21) ——— and BROWN, S. M.
1924. REPLACEABLE BASES IN SOILS. Calif. Agr. Expt. Sta. Tech. Paper 15, 39 p.
(22) KERR, H. W.
1928. THE NATURE OF BASE EXCHANGE AND SOIL ACIDITY. Jour. Amer. Soc. Agron. 20: 309–335, illus.
(23) MCCOOL, M. M.
1927. RESULTS OF SOME PHYSICAL AND CHEMICAL STUDIES ON SOIL COLLOIDS. Jour. Amer. Soc. Agron. 19: 289–297.
(24) MAGISTAD, O. C., and BURGESS, P. S.
1928. THE USE OF ALCOHOLIC SALT SOLUTIONS FOR THE DETERMINATION OF REPLACEABLE BASES IN CALCAREOUS SOILS. Ariz. Expt. Sta. Tech. Bul. 20, p. 481–497.
(25) MARBUT, C. F.
1928. A SCHEME FOR SOIL CLASSIFICATION. First Internatl. Cong. Soil Sci. 1927, Proc. and Papers, Comm. 5, v. 4, p. 1–31.
(26) MARTIN, F. J., and DOYNE, H. C.
1930. LATERITE AND LATERITIC SOIL IN SIERRA LEONE, II. Jour. Agr. Sci. [England] 20: [135]–143, illus.
(27) MATTSON, S.
1926. THE RELATION BETWEEN THE ELECTROKINETIC BEHAVIOR AND THE BASE EXCHANGE CAPACITY OF SOIL COLLOIDS. Jour. Amer. Soc. Agron. 18: 458–470, illus.
(28) OLMSTEAD, L. B., ALEXANDER, L. T., and MIDDLETON, H. E.
1930. A PIPETTE METHOD OF MECHANICAL ANALYSIS OF SOILS BASED ON IMPROVED DISPERSION PROCEDURE. U. S. Dept. Agr. Tech. Bul. 170, 23 p., illus.
(29) ROBINSON, W. O.
1922. THE ABSORPTION OF WATER VAPOR BY SOIL COLLOIDS. Jour. Phys. Chem. 26: 647–653.
(30) ——— and HOLMES, R. S.
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U. S. Dept. Agr. Bul. 1311, 42 p.
(31) TAMM, O.
1920. MARKSTUDIER I DET NORDSVENSKA BARRSKOGS-OMRÅDET. Meddel. Statens Skogsförsöksanst. [Sweden] Häft 17, no. 3, p. 49–300.

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VARIATIONS OF THE COLLOIDAL MATERIAL EXTRACTED FROM THE SOILS OF THE MIAMI, CHESTER, AND CECIL SERIES

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CONTENTS

	Page
Introduction	1
Methods	2
Description of samples	4
The Miami soils	5
The Chester soils	7
The Cecil soils	8
Composition and properties of the colloidal material isolated from soils of three series	10
General relations between the profiles	15
Composition and properties of the colloidal material isolated from soils of three series—Continued.	
The mean variations	17
Differences in composition of colloids from soils of the different series	19
Summary	22
Literature cited	22

INTRODUCTION

The work, the results of which are recorded, discussed, and interpreted in the following pages, was undertaken for the purpose of making a critical examination into the character of certain well-known American soils through an extensive study and comparison of the characteristics of their colloidal constituents. Soils belonging to three series were selected for the study, the Chester, Miami, and Cecil series, as defined and established by the work of the soil survey of the Bureau of Chemistry and Soils. According to the established definition of a soil series, all members in each series are alike in all characteristics except texture (coarseness or fineness of the soil particles) of the surface layer. Each member, or, as it is usually designated in the publications of the Bureau of Chemistry and Soils, each type, is characterized by a different surface texture. It is important to ascertain whether the colloid of a given soil series is similar in the various types of the series, and it is the purpose of this investigation to throw some light on these problems with respect to these three soil series. A sufficient number of widely separated profiles are included to represent fairly well the entire area of each soil series and to permit mathematical calculations of variability. Various horizons of the profile are investigated in order to determine the type of varia-

tion peculiar to the series shown by the colloidal material through the soil profile. This investigation is supported by a recent bulletin by M. S. Anderson and Horace G. Byers (*1*),[1] which presents a similar study of the colloids of soil groups of widely different types.

Previous investigations (*2*, *18*) have shown that the character of the colloidal material is fairly well correlated with the molecular ratios of silica to the sesquioxides of aluminum and iron, and that this ratio varies greatly for the colloids of different soils. In an investigation (*10*) on the variability of the colloidal material in a well-defined soil type, Leonardtown silt loam, the senior author found that colloidal material is fairly constant in composition and properties, not only in the A horizons but also in the B_1 and B_2 horizons. Ninety-five per cent of the inorganic material is composed of silica, alumina, ferric oxides, and their combined water. The silica-sesquioxide ratio is practically constant for all horizons. Of the four constituents the variation of the combined water is greatest, having a coefficient of variability of 6.

The same publication (*10*) also contained a review of publications by Hall and Russell (*8*), G. W. Robinson (*14*), Bradfield (*4*), and Robinson and Holmes (*18*), which reported composition of soil colloids. Recently, in 1929, R. E. Stephenson published a paper (*19*) on Colloidal Properties of Williamette Valley Soils, and in 1930, I. A. Denison of this bureau published an article (*6*) on the Chemical Composition of Colloidal Material Isolated from the Horizons of Various Soil Profiles. In no case, except that of the Leonardtown silt loam, is there found data sufficiently comprehensive to give the specific information sought.

METHODS

The colloidal material was separated from the soil in much the same manner as described in a previous publication (*10*), except for preparation of the suspensions for the centrifuge. For this work a mechanical agitator was devised to do the work that had formerly been done by hand. This agitator (fig. 1) consists of the following parts: A container, *a*, of about 5 gallons capacity; a shaft, *b*, upon which are mounted five small screw propellers, *c;* and a scrubber, *d*, composed of brass rods and a wire cloth made to fit snugly the bottom of the container, *a*. The shaft is mounted within the container, *a*, with a rubber bearing, *e*, at the bottom, and a steel thrust ball-bearing, *f*, at the top. The shaft is revolved by an electric motor in the direction to give the propellers a lifting effect and at a velocity of from 1,800 revolutions a minute when empty to 900 when full.

The suspensions for the centrifuge are prepared with the agitator in the following manner: From 50 to 200 grams of soil, depending on the quantity of colloid present as estimated by the water-absorption method (*15*) is mixed with about 1 gallon of water and stirred, while enough ammonia water is added to make it slightly alkaline to phenol-phthalein. This mixture is poured into the agitator and stirred for 20 minutes. While the agitator is running the volume of water is gradually increased during the next 10 minutes to about full

[1] Italic numbers in parentheses refer to Literature Cited, p. 22.

capacity. At this time the motor is stopped, and after about 15 minutes the suspended material is drawn off. More water is added to the material left in the container of the agitator, and the operation is repeated. When the noncolloidal particles which settle out in the agitator become clean they are removed and discarded. The suspensions from the agitator are combined and passed through the

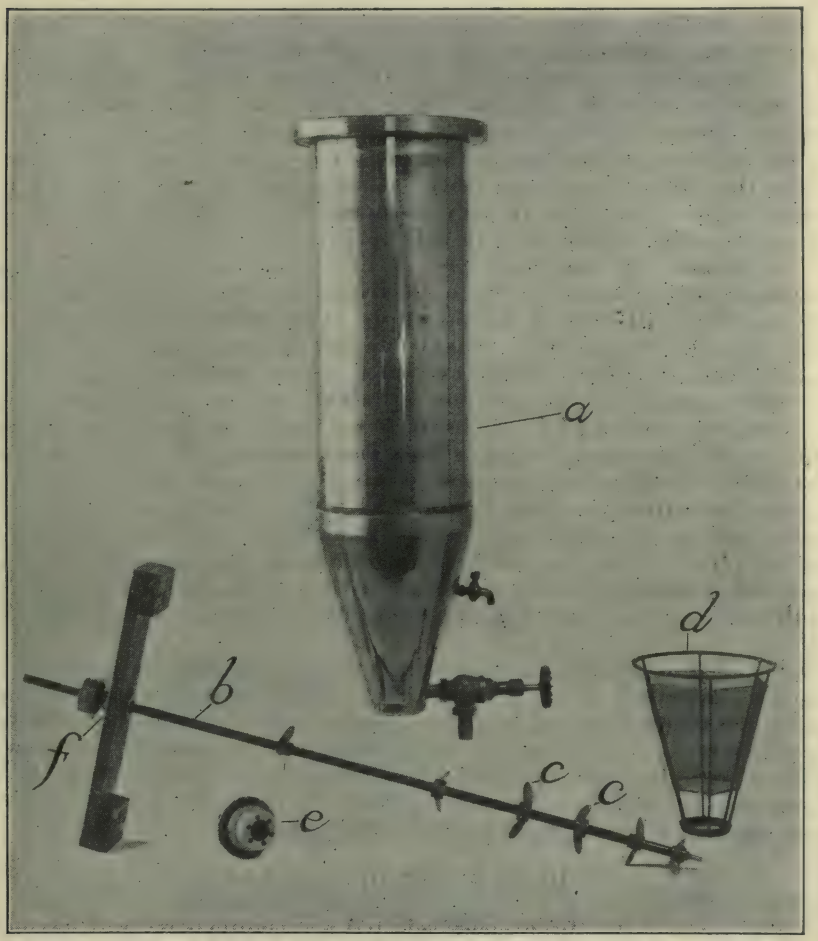

FIGURE 1.—Agitator for the purpose of separating colloidal material from the soil: *a*, Container; *b*, shaft; *c*, screw propeller; *d*, scrubber; *e*, rubber bearing; *f*, thrust ball bearing

supercentrifuge. The residue which collects in the centrifuge bowl is removed and returned to the agitator, and again suspended as before. The successive residues are returned until negligible quantities of colloid are obtained. This mechanical device enabled the authors to separate the colloidal material from two soil samples, of 200 grams each, per day. The material separated is considered a fair sample of the colloid of the soil, since in each case 75 per cent or more of the total colloid was separated.

The analysis of the colloidal material was made by the fusion method. It is commonly supposed that this material, since it is composed of very small particles, is soluble in acids. Experience has proved that this is not true, therefore the same procedure for analysis was followed as for a soil. The procedure for soil analysis is a modification of the method described by Hillebrand (*9*) for the analysis of silicate rock. The complete method for the analysis of soils is described in a bulletin by Robinson (*17*) of this bureau. Organic matter was determined by the dry-combustion method. The carbon dioxide evolved is multiplied by the factor 0.471. The combined water is taken to be the ignition loss less the organic matter. The figures given for the combined water are therefore subject to an error involved in the use of the Van Bemmelen factor. It is probable that this factor is rather constant for surface soils of the same series though it may vary considerably in different series as has been found by earlier work in this bureau (*16*).

Hydrogen-ion determinations of the whole soil were made electrometrically with a hydrogen electrode in a vessel of the bubbling type. These pH values should apply to the colloidal material since the colloid component is responsible for the reaction of the whole soil. The pH values of the extracted colloid were not measured as it was necessary to use ammonia in extracting this colloidal material.

Previous studies (*2*, *7*, *15*) have shown that in an atmosphere where the vapor pressure of water is high the quantities of water adsorbed by different soil colloids are comparatively constant, but vary greatly when the vapor pressure is low. Therefore the quantity of water adsorbed by the whole soils when kept over 3.3 per cent by weight of sulphuric acid was used in determining the colloidal content, and the quantity of water adsorbed by the colloids over 30 per cent of sulphuric acid was used in the study of the variations occurring in them.

The base-exchange capacity was estimated from the quantity of barium adsorbed from a neutral normal barium-chloride solution. The procedure followed was the same as that described in a previous publication (*10*), except for colloids containing calcium carbonate. These samples were treated with normal ammonium chloride to remove the adsorbed barium, instead of twentieth-normal hydrochloric acid which was used on all other samples.

DESCRIPTION OF SAMPLES

The soils of the three series selected are confined to, and have developed in, the eastern half of the United States under the influence of high rainfall and a temperature ranging from temperate to warm temperate. They have developed under a forest cover and are characterized by a podsolic profile.

The Chester and Miami soils are members of the gray-brown podsolic group as defined originally by Marbut (*12*, *13*) under the name of brown forest soils, but to which at a later date the name as just given and now generally used in this country was applied by Baldwin (*3*). These soils are important agriculturally and are extensive in area as indicated by the following descriptions furnished by the soil survey division of this bureau. The entire area of each series is fairly well represented by the samples selected for this investigation.

As may be observed, each soil series is represented by nine or more profiles. All samples were selected by trained field men of the soil survey.[2] Particular care was exercised to ascertain that each sample had well-developed characteristics of its series. The samples of the soil collected were not composited, but each was taken from a single hole which represented an area of only a few square inches.

THE MIAMI SOILS

Miami silt loam is a member of a soil group which occurs in the Middle West, south of the true podsol soils, and is designated as a gray-brown podsolic soil. The samples reported in this investigation represent fairly well the entire area covered by Miami silt loam which is the most extensive and representative type of the Miami series. The Miami silt loam has a well-defined soil profile developed from medium to heavy textured glacial till under the influence of a deciduous forest and good but not excessive drainage. The following description indicates in some detail the field characteristics of Miami silt loam:

The surface leaf litter, consisting almost entirely of a loose accumulation of dried leaves, is only moderately abundant. The leaf mold, consisting of the somewhat packed and matted, disintegrated, and partly decomposed leaves and other plant remains, is thin; in most places it was observed to be from one-eighth to one-fourth inch thick. Beneath the organic-matter covering the mineral soil profile begins. In the Miami silt loam the texture profile is well developed and clearly defined. To a depth of some 12 inches, the soil is silt loam, from 12 to about 35 inches clay loam, and below that loam. These texture horizons may be taken as the primary horizons of the soil profile and designated A, B, and C. The A and B horizons together constitute the true soil, and the C horizon is the somewhat altered parent material, which ranges from medium to heavy textured glacial till.

Each primary horizon of the texture profile has characteristics which further subdivide it. The surface 2 inches of the mineral soil is very dark grayish brown in color, rich in organic matter, and when gently shaken out, falls into small soft roundish particles, from one-sixteenth to one-eighth inch in diameter, which cling to the plant roots. These particles are easily crushed when either moist or dry, and the whole mass is friable. There is a tendency to an irregular horizontal laminated or platy structure. Worm casts, wormholes, plant roots, and plant rootlets are very numerous. The dark color gradually fades with depth through the A horizon, the platy structure or breakage becomes more pronounced until the B horizon is approached, and the finer-grained structure is less pronounced. There is decreasing evidence of worm work and fewer plant roots and rootlets, but darker irregular channels occurring through the mass are probably filled-in wormholes.

With the change in texture from the A to the B horizon there is also a change in structure. The material of the B horizon breaks into irregular lumps ranging from one-fourth to 1 inch in diameter. These lumps are, in general, smaller at the top of the horizon, be-

[2] The Miami soil samples were collected by M. Baldwin, W. E. Thorp, and T. M. Bushnell. The Chester soil samples were collected by C. F. Marbut, S. O. Perkins, and W. E. Hearn. The Cecil soil samples were collected by W. E. Hearn and R. Wildermuth.

coming larger with depth. These small blocks, although fairly soft when moist and becoming a plastic mass with moderate pressure, are so hard when dry that they can not be crushed by ordinary direct pressure of thumb and finger. Within this layer (horizon B), the color of the soil material varies. The upper 4 or 5 inches are light brown or yellow brown on the faces of the structure blocks, with gray coatings in places. The interiors of the little blocks are more yellow, and a powdered mass of the material drys to light brownish yellow. There is a gradual transition to browner colors downward, at least to duller browns on the outside of the blocks, with more yellow in the interiors. A characteristic feature is a thin gell-like coating on the surface of the blocks, which is especially evident when they are moist. The lower 4 to 6 inches of the B horizon are marked by very dark-brown or black coatings on the structure blocks. Little pores and irregular tubes of about the diameter of a small needle are common features of the B horizon and are especially noticeable in the upper part. Plant roots and rootlets not only follow the breakage planes but penetrate the blocks. The root channels, especially of dead roots, are incased by darker-colored material.

The C horizon is calcareous glacial till of Late Wisconsin age. The upper 5 to 10 feet are light grayish yellow in color, firm and hard when dry but not extremely compact like some of the glacial drift farther east. The material tends, on exposure in banks, to develop irregular joint planes which separate the mass into angular blocks. Small stones and pebbles scattered through the mass consist of limestone, dolomite, shale, sandstone, granite, and other igneous and metamorphic rocks.

The Miami soils were developed under a normal rainfall of about 34 inches and under a mean annual temperature range for the area sampled of from 47° to 50.7° F.

A description of samples of Miami silt loam taken in various localities, arranged in order from north to south, is given in Table 1.

TABLE 1.—*Description of Miami silt loam samples*

Profile No.	Location of sample	Horizon	Depth	Colloid content	pH
			Inches	*Per cent*	
1	Eaton County, Mich., southeast corner of NW. ¼ sec. 12, T. 4 N., R. 5 W.	A	6–10	9.6	4.90
		B	18–30	25.2	5.40
		C	34–40	5.2	7.80
2	Washington County, Mich., 5 miles southeast of Ann Arbor	A	0–8	11.9	5.85
		B	8–30	35.8	6.30
		C	54+	26.6	8.15
3	Branch County, Mich., southeast ¼ sec. 19, T. 8 N., R. 5 W.	A	2–8	7.9	4.60
		B	9–36	33.4	6.10
		C	40–60	29.3	8.20
4	Miami County, Ind., 3.5 miles northwest of Peru	A	4–10	14.7	5.25
		B	12–20	36.9	7.05
5	Miami County, Ind., 2 miles south of Peru	A	6–10	11.6	6.15
		B	15–20	36.2	5.30
		C	40–50	19.0	8.58
6	Blackford County, Ind.	A	4–7	16.9	6.30
		B	11–18	37.6	5.90
		C	38–42	22.7	8.45
7	Grant County, Ind., 2 miles east of Gas City	A	3–9	10.1	6.70
		B	10–26	33.6	4.80
		C	32–42	19.5	8.30
8	Hancock County, Ind., 4.5 miles south of Greenfield	A	2–12	15.8	4.95
		B	16–32	36.6	5.22
		C	36+	14.1	8.58
9	Rush County, Indiana	A	5–14	13.9	5.53
		B	14–18	18.1	4.98
		C	60–64	12.1	8.67

THE CHESTER SOILS

The soils of the Chester series occupy an important area in the northern part of the piedmont plateau in Virginia, Maryland, Pennsylvania, and New Jersey. They have developed under a forest cover in which oak, chestnut, and hickory constitute the dominant trees. The parent material from which they have developed was accumulated in place by the residual decay of crystalline gneisses and schists some of which are granitic. As a whole, therefore, they contain a larger sand constituent than the Miami soils. The surface soils range from loams to sandy loams where the profile is normally developed, rather than silt loams, loams, and clay loams as in the Miami soils.

In virgin forests where most of the samples used were collected, the surface is covered by a layer of leaves and leaf mold, the latter being rather well decomposed but rarely having lost all trace of its origin. In extremely rare cases it is well granulated. The topmost 2 to 4 inches of mineral soil is dark colored, and in places where the texture is rather heavy it may be moderately well granulated, but, partly because of its dominant, rather coarse texture, it is not so well granulated as the corresponding layer in the Miami soils. This layer is usually described as the A_1 horizon and is underlain by the A_2 horizon consisting of yellow, reddish-yellow, or brownish-yellow material which is dominantly loam or sandy loam. The material in this horizon is, as a rule, less clearly laminated than the A_2 horizon in the Miami soils and is practically structureless. These two subhorizons range from a total thickness of 5 to about 10 inches.

The B horizon consists of brown, strong yellowish-brown, or reddish-brown clay loam or clay. The transition from the A horizon to the B horizon is in most places gradual. The material of the B horizon breaks into moderately well-defined small angular particles ranging in size from a quarter of an inch or less to half an inch in diameter. This structure, or regular breakage, is best developed in the heavier members of the series, where it is as noticeable as in the B horizons of the Miami soils, but in the dominant members it is less perfect. The outsides of the particles are usually more deeply colored than the insides so that a broken fragment of the horizon, if the break has taken place along the outsides of the particles, is redder or more brown than the crushed material.

The top of the horizon is heaviest and best developed in all its characteristics, and there is a gradual merging with depth into the underlying parent material, or C horizon, consisting of loose material resulting from the disintegration and decomposition of the underlying crystalline rocks. This material is usually yellow to faint red and contains more or less partly decomposed and undecomposed minerals in which mica is often a noticeable constituent. In the A and B horizons mica may be present, more often in the latter, and quartz is usually present, but other identifiable minerals are not usually present.

The Chester soils were developed under a rainfall ranging from about 45 inches in northern New Jersey to about 50 inches in north-central North Carolina. The average annual temperature ranges between 47° and 53° F. in the northern end of the belt and between 57° and 63° in the southern end.

A description of samples of the Chester soils taken in various localities is given in Table 2.

TABLE 2.—*Description of samples of the Chester soils*

Profile No.	Location of sample	Horizon	Depth	Color	Colloid content	pH
			Inches		*Per cent*	
10	Warren County, N. J	B	10–16	Yellow	22.3	6.30
11	do	B	10–20	do	25.0	7.50
12	Somerset County, N. J	B	16+	do	20.4	6.32
13	Chester County, Pa., 3 miles northeast of West Chester.	A	0–9	Brown	21.2	5.72
		B	9–28	Reddish brown	31.3	6.05
		C	40+	Yellowish brown	21.5	6.70
14	Lancaster County, Pa	B	12–20	Grayish purple	27.6	4.75
15	do	A	1–17	Brown	21.0	4.90
16	Cecil County, Md., 1 mile west of Blueball.	A	1–8	do	31.1	
		B	8–30	Grayish yellow	32.7	4.78
		C	42–60	Yellow	18.9	5.56
17	Cecil County, Md., one-fourth mile west of Colora.	A	0–9	Brown	14.2	6.50
		B	9–28	Yellow	21.6	5.14
		C	28–50	do	11.8	6.05
18	Cecil County, Md., 1 mile west of Appleton.	A	0–7	Grayish brown	15.0	5.45
		B	7–32	Yellow	25.5	5.15
		C	44–60	Yellow brown	6.4	5.42
19	Cecil County, Md., 1 mile northwest of Rolandsville.	A	0–10	Deep brown	18.6	5.60
		B	10–30	Brown	25.3	6.20
20	Harford County, Md	A	1–9	Light brown	16.0	4.53
		B	9–28	Yellowish brown	26.0	4.80
		C	40–60	Yellow	7.0	4.95
21	Montgomery County, Md., 3 miles northwest of Rockville.	A	0–8	Brown	16.0	4.47
		B	8–34	Reddish brown	34.0	5.07
		C	54+	Red brown	17.0	4.90
22	Montgomery County, Md., one-fourth mile northwest of Glenmont.	A	0–8	Light brown	8.5	
		B	8–32		24.8	
23	Arlington County, Va	B	12–18	Light yellow		
24	Fairfax County, Va	A	0–7	Yellowish brown	14.3	

THE CECIL SOILS

The soils of the Cecil series occupy the southern part of the piedmont region of the eastern part of the United States, the belt crossing North Carolina, South Carolina, and Georgia, and ending in the eastern part of Alabama. These soils have developed from material accumulated in place by the residual decay of crystalline rocks, mainly schists and gneisses, some of which are granitic and practically all of which contain free quartz. The material is geologically identical with that from which the Chester soils have developed, and the Cecil soils also have developed under forest cover and in a region of high rainfall. The temperature under which development has taken place, however, is higher than for the Chester soils. The forest cover consists mainly of oak, together with chestnut and some pine.

The typical profile of the dominant fully developed member of the Cecil series, the sandy loam, consists of the following layers: A thin cover of leaf mold and loose leaves of the same character as in the Chester soils but thinner. The leaf mold is underlain by a dark-colored sandy layer, ranging to about 4 inches in thickness and usually structureless. The organic matter is not well incorporated with the mineral constituents and disappears rather rapidly under cultivation. Beneath the dark-colored layer, designated as

in the Chester and Miami soils the A_1 horizon, lies a gray, pale-yellow, or reddish-yellow horizon, the color depending on the stage of podsolic development, and this in turn depending, all other conditions being equal, on the texture of the material. If the material is rather sandy, development will be comparatively rapid, the horizon will soon become very sandy through eluviation and will become progressively light in color with the increasing sandiness. The dominant color, however, of this horizon, designated as A_2, is pale yellow. The soil material is structureless, as a rule, but may show faint lamination.

The B horizon underlies the A_2 horizon, the transition being comparatively rapid, usually more so than in the Chester or Miami soils, and the difference in texture between the A and B horizons is greater than in the soils of either of the other two series. The color of the B horizon is strongly reddish yellow, yellowish red, or orange; the texture is clay loam or sandy clay; and the breakage into angular particles is more definite than in the B horizon of the Chester soils. The outsides of the structure particles are red, and the insides yellowish red. Small amounts of dark-colored organic matter in the form of insect casts and fillings of insect borings are present in the A_2 and B horizons, but they constitute a less important feature of the soil than in either the Miami or Chester soils. The best-developed and most characteristic part of the B horizon is the upper 6 to 12 inches. The soil material merges gradually with depth into the loose but still red disintegrated rock material designated as the C horizon. The thickness of the B horizon is about 3 feet, being greater than that of the corresponding horizons in the Miami and Chester soils.

The Cecil soils were developed under a rainfall of about 50 inches in the northern part of the belt in North Carolina and about 55 inches in the southern part, in Alabama. The average summer temperature of the northern part of the belt is a little less than 75° F., and that of the southern part of the belt in Georgia is about 80°. The average winter temperatures of the two parts of the belt are 40° and 50°, respectively.

The Cecil soils are podsolic, but because of their extensive eluviation, leaching of silica and bases, and their more intense red color they have been placed in the broad group of red soils by the field service of the Bureau of Chemistry and Soils.

Descriptions of several samples of Cecil soils are given in Table 3.

22769°—30——2

TABLE 3.—*Description of samples of the Cecil soils*

Profile No.	Location of sample	Horizon	Depth	Color	Colloid content	pH
			Inches		*Per cent*	
25	Goochland County, Va.	A	0–8	Grayish yellow	9.6	4.58
		B	12–30	Red	25.2	4.55
		C	60+	Light red	5.2	4.45
26	Rockingham County, N. C.	A	4–10	Grayish yellow	8.9	4.70
		B	16–38	Red	44.7	4.65
		C	70+	Yellowish red	20.7	4.42
27	Davie County, N. C.	A	1–8	Grayish yellow	6.3	4.85
		B	20–50	Red	45.3	4.62
		C	50+	Yellowish red	27.3	5.58
28	Rutherford County, N. C., 6.2 miles west of Rutherfordton.	A	0–5	Reddish brown	20.1	4.80
		B	5–36	Deep red	51.5	5.15
		C	72–96	Brownish red	30.9	5.37
29	Rutherford County, N. C.	B	6–40	Red	38.1	4.90
30	Clarke County, Ga., 1 mile north of Godfrey's store.	A	1–5	Reddish brown	11.2	5.70
		B	5–60	Deep red	54.0	5.30
		C	110–130	Yellowish red	29.7	4.50
31	De Kalb County, Ga.	B	20–28	Red	49.3	5.15
32	Wilkes County, Ga.	B	12–25	do	38.1	5.20
33	Wilkes County, Ga., 2.5 miles northeast of Washington.	A	0–9	Dark red	10.2	5.40
		B	9–36	Brownish red	31.0	
34	Oconee County, Ga.	B	18–28	Red	47.5	4.83
35	Henry County, Ga.	B	18–30	do	46.5	5.04
36	Fayette County, Ga.	B	8–15	do	41.3	5.06
37	Butts County, Ga.	B	10–20	Deep red	47.8	4.96
38	Meriwether County, Ga.	B	15–25	Red	48.5	5.76
39	Troup County, Ga., 1 mile south of Lebanon.	A	2–6	Yellowish brown	4.3	5.10
		B	20–35	Deep red	43.3	4.85
		C	75–90	Purplish red		4.48
40	Troup County, Ga., 6 miles east of Lagrange.	B	10–42	Deep red	38.9	4.64
		C	91–180	Yellowish red		4.33
41	Chambers County, Ala., 6 miles west of Lanett.	A	0–7	Reddish brown	20.5	5.67
		B	8–24	Deep red	42.4	5.20
		C	25–59	Red		4.85

COMPOSITION AND PROPERTIES OF THE COLLOIDAL MATERIAL ISOLATED FROM SOILS OF THREE SERIES

The composition and properties of the Miami, Chester, and Cecil colloids are given in Tables 4, 5, and 6, respectively. In order to obtain more comparable data for the inorganic constituents, they are calculated on the inorganic basis, that is, weight of oven-dried material less organic matter. This mode of calculation eliminates the effect of the variable quantities of organic matter. The organic matter and properties are calculated on the colloids as a whole dried to constant weight at 100° C.

TABLE 4.—*Composition and properties of colloidal materials isolated from Miami silt loam*

Profile No.	Location of sample	Horizon	Depth	SiO_2	Al_2O_3	Fe_2O_3	Combined H_2O	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	MnO	Organic matter	Molecular ratio, $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Base exchange capacity per 100 grams	H_2O vapor adsorbed per 100 grams
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Milliequivalents*	*Grams*
1	Eaton County, Mich	A	6–10	49.30	25.30	9.70	8.71	0.53	2.45	2.71	0.21	0.87	0.23	0.14	0.15	5.65	2.65	31.7	7.3
		B	18–30	48.00	24.21	11.16	7.96	.81	3.09	3.62	.25	.82	.17	.20	.10	1.69	2.59	37.5	9.4
		C	34–40	48.28	23.29	11.26	7.41	1.25	3.42	4.02	.34	.71	.20	.13	.12	1.46	2.68	42.6	10.0
2	Washtenaw County, Mich	A	0– 8	50.84	25.45	9.23	6.44	.95	2.13	3.48	.35	.85	.28	.12	.21	6.87	2.75	31.7	5.9
		B	8–30	48.42	25.26	10.84	7.34	.93	2.76	4.58	.26	.80	.12	.23	.07	1.31	2.55	33.8	8.6
		C	54+	44.58	22.13	9.40	5.67	5.15	3.25	4.73	.33	.62	.19	.13	.07	1.10	2.69	23.7	6.3
3	Branch County, Mich	A	2– 8	51.50	25.42	8.25	8.32	.20	2.17	2.74	.26	.92	.29	.21	.18	4.82	2.84	22.9	4.5
		B	9–36	47.50	25.58	10.85	7.04	.66	2.75	4.28	.10	.64	.15	.10	.07	1.37	2.48	33.7	8.1
		C	40–60	47.85	24.48	9.96	6.82	1.73	3.14	4.73	.15	.66	.22	.10	.05	1.35	2.62	34.3	6.9
4	Miami County, Ind	A	4–10	48.97	24.76	10.16	8.42	.92	2.21	2.61	.21	.64	.31	.14	.24	4.05	2.66	29.3	9.0
		B	12–20	47.44	24.28	11.78	7.67	.88	2.87	3.45	.18	.58	.20	.12	.14	1.72	2.52	42.5	9.5
5	Do	A	6–10	49.87	24.25	9.97	8.39	.96	1.97	2.59	.13	.60	.38	.23	.24	5.77	2.75	31.3	6.6
		B	15–20	48.08	25.14	11.11	7.75	.88	2.48	2.86	.14	.51	.23	.10	.09	1.88	2.53	40.3	9.9
		C	40–50	44.91	23.15	10.24	7.44	3.73	3.11	4.20	.24	.48	.19	.14	.09	1.64	2.55	34.2	6.7
6	Blackford County, Ind	A	4– 7	50.81	25.70	8.33	6.49	.81	2.43	3.03	.25	.66	.19	.22	.19	6.50	2.78	36.8	6.1
		B	11–18	47.65	25.64	11.13	7.72	.77	2.60	3.95	.15	.55	.12	.15	.12	1.77	2.48	39.1	8.6
		C	38–42	48.43	24.40	10.47	7.04	2.27	2.88	4.83	.20	.57	.17	.13	.08	1.12	2.64	32.8	6.5
7	Grant County, Ind	A	3– 9	51.81	24.50	8.61	8.00	.90	2.16	2.40	.20	.76	.30	.25	.13	5.70	2.92	32.9	5.6
		B	10–26	48.18	25.20	11.77	7.89	.54	2.54	3.27	.10	.69	.15	.11	.10	1.71	2.37	37.9	9.3
		C	32–42	46.56	23.25	10.57	6.34	1.46	2.98	4.76	.29	.67	.16	.19	.10	1.30	2.57	35.2	7.0
8	Hancock County, Ind	A	2–12	47.47	27.58	9.89	9.23	.92	1.17	2.48	.34	.74	.40	.29	.28	6.47	2.39	36.5	7.1
		B	16–32	47.53	25.15	12.45	8.44	.70	2.40	2.71	.07	.59	.22	.10	.14	1.96	2.43	40.5	9.5
		C	36+	47.13	24.25	11.45	7.23	1.50	3.09	4.28	.16	.60	.21	.12	.09	1.96	2.53	36.4	7.6
9	Rush County, Ind	A	5–14	47.48	25.25	10.09	9.98	.62	2.10	1.97	.16	.68	.20	.21	.20	8.03	2.50	41.1	6.9
		B	14–18	48.45	25.17	11.76	9.31	.47	2.09	2.06	.10	.67	.16	.28	.16	4.43	2.51	43.3	8.3
		C	60–64	42.38	21.75	9.64	5.93	8.00	3.40	4.20	.21	.56	.15	.12	.08	0.94	2.57	51.2	6.3
	Mean	A	-------	49.78	25.34	9.36	8.22	.76	2.09	2.67	.23	.75	.29	.20	.20	5.95	2.69	32.7	6.5
		B	-------	47.92	25.06	11.43	7.90	.74	2.62	3.42	.15	.65	.17	.15	.11	1.98	2.49	38.7	9.0
		C	-------	46.26	23.34	10.37	6.73	3.14	3.16	4.47	.24	.61	.19	.13	.08	1.36	2.61	36.3	7.2
	Standard deviation	A	-------	1.52	.90	.73	1.04	.24	.35	.37	.07	.10	.07	.05	.04	1.09	.15	4.86	1.20
		B	-------	.37	.47	.51	.62	.15	.28	.74	.06	.10	.04	.06	.03	1.20	.06	3.20	.59
		C	-------	1.98	.95	.67	.63	2.23	.17	.30	.06	.07	.02	.03	.02	.31	.05	5.50	1.14
	Coefficient of variability	A	-------	3.1	3.5	7.8	12.6	31.5	16.7	13.8	30.4	13.3	24.1	25.0	20.0	18.3	5.5	14.8	18.5
		B	-------	0.8	1.9	4.5	7.8	20.2	10.7	21.6	40.0	15.3	23.5	40.0	27.3	60.3	2.4	8.2	6.5
		C	-------	4.3	4.1	6.5	9.4	71.0	5.4	6.7	25.0	11.5	10.5	23.1	25.0	22.5	2.1	15.2	15.8

TABLE 5.—*Composition and properties of colloidal materials isolated from soils of the Chester series*

Profile No.	Location of sample	Horizon	Depth	SiO_2	Al_2O_3	Fe_2O_3	Combined H_2O	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	MnO	Organic matter	Molecular ratio, $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Base exchange capacity per 100 grams	H_2O vapor adsorbed per 100 grams
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Milliequivalents*	*Grams*
10	Warren County, N. J.	B	10–16	40.09	32.76	11.83	12.87	0.55	0.86	0.65	0.08	0.55	0.10	0.08	0.04	1.07	1.68	15.3	6.7
11	do	B	10–20	39.30	32.88	12.49	13.14	.49	.91	.40	.02	.54	.13	.14	.05	1.76	1.68	17.1	6.3
12	Somerset County, N. J.	B	16+	34.56	28.31	18.86	14.18	.65	1.23	.87	.05	1.06	.47	.18	.13	2.86	1.45	21.1	8.5
13	Chester County, Pa.	A	0– 9	33.67	29.35	16.08	12.98	.86	2.84	.94	.17	1.30	.46	.22	.58	11.71	1.44	29.9	6.8
		B	9–28	33.19	27.69	20.95	11.96	.34	2.25	.95	.06	1.42	.45	.47	.26	4.22	1.38	18.4	6.5
		C	40+	35.46	27.51	19.24	12.34	.40	1.70	1.13	.07	.94	.49	.23	.17	3.49	1.51	18.2	6.7
14	Lancaster County, Pa.	B	12–20	39.11	29.54	16.15	12.10	.41	1.10	1.37	.06	.74	.18	.13	.14	1.62	1.66	18.8	7.2
15	do	A	1– 7	35.58	33.45	13.48	12.66	.35	.95	1.43	.21	.56	.37	.18	.35	6.30	1.43	18.5	6.4
16	Cecil County, Md.	A	1– 8	34.06	31.87	14.27	14.15	.09	2.43	.41	.01	.55	.89	.41	.35	10.50	1.41	27.7	6.4
		B	8–30	40.46	28.70	15.35	11.35	.10	1.57	.88	.02	.51	.41	.09	.08	1.45	1.78	26.0	9.1
		C	42–60	38.45	35.14	8.27	15.48	.24	.63	.38	.07	.23	1.27	.17	.09	3.90	1.61	18.7	5.7
17	do	A	0– 9	38.07	33.05	10.45	12.60	.71	1.66	1.35	.06	.67	.27	.27	.55	7.02	1.65	27.9	6.5
		B	9–28	38.76	32.28	12.73	12.26	.39	1.33	1.16	.15	.72	.15	.11	.09	1.80	1.62	18.2	8.0
		C	28–50	39.74	34.95	9.24	12.68	.21	.86	.99	.02	.56	.14	.12	.17	1.97	1.64	14.1	7.1
18	do	A	0– 7	39.93	30.91	11.83	12.67	.56	1.51	1.08	.14	.69	.49	.37	.28	7.77	1.76	25.2	6.7
		B	7–32	42.56	28.10	13.85	10.61	.44	1.55	1.29	.12	.99	.20	.10	.10	1.80	1.98	25.7	9.2
		C	44–60	42.73	34.52	7.60	12.48	.36	.64	.61	.08	.32	.28	.26	.20	2.90	1.84	15.0	6.1
19	do	A	0–10	33.49	35.40	12.36	14.11	.53	1.38	.94	.02	.59	.37	.29	.27	6.15	1.31	22.5	6.3
		B	10–30	37.51	32.80	12.55	12.85	.35	1.21	.95	.02	.58	.38	.18	.09	1.32	1.55	19.9	7.8
20	Harford County, Md.	A	1– 9	37.96	31.27	14.01	11.92	.52	1.28	1.06	.09	.52	.32	.37	.18	4.51	1.60	19.9	6.4
		B	9–28	39.28	30.38	15.12	11.50	.32	.70	1.02	.06	.63	.27	.18	.09	2.03	1.66	18.1	7.5
		C	40–60	34.67	31.34	18.10	11.23	.31	.85	.97	.18	.49	.81	.92	.13	6.53	1.37	12.0	5.0
21	Montgomery County, Md.	A	0– 8	34.50	30.79	17.22	12.72	.36	1.17	.81	.05	.54	.49	.46	.38	7.52	1.40	22.7	7.3
		B	8–34	39.31	28.28	14.71	11.42	.45	1.38	.99	.05	.57	.22	.16	.15	2.24	1.77	26.9	10.5
		C	54+	37.30	30.56	16.56	10.88	.47	.98	1.28	.13	.58	.28	.40	.12	2.17	1.55	13.5	6.0
22	do	A	0– 8	40.62	31.23	11.74	12.25	.97	.23	1.29	.33	.58	.20	.09	.08	4.11	1.77	29.0	7.2
		B	8–32	42.14	27.90	10.58	10.80	.65	1.28	1.85	.26	.81	.15	.05	.37	4.99	1.79	22.7	6.8
23	Arlington County, Va.	B	12–18	38.19	30.17	16.30	10.67	.54	1.32	1.16	.18	.58	.20	.21	.05	4.16	1.59	20.6	8.8
24	Fairfax County, Va.	A	0– 7	36.85	29.50	16.86	12.59	.18	3.03	.90	.08	1.14	.31	.07	.23	5.54	1.54	20.7	6.5
	Mean	A		36.47	31.68	13.83	12.86	.51	1.65	1.02	.12	.71	.42	.28	.33	7.11	1.53	24.4	6.6
		B		38.80	29.98	14.71	11.98	.44	1.28	1.04	.09	.75	.25	.17	.14	2.41	1.66	20.6	7.8
		C		38.06	32.33	13.16	12.51	.33	.93	.89	.09	.52	.54	.35	.15	3.49	1.59	15.3	6.1
	Standard deviation	A		2.47	1.76	2.24	.68	.27	.83	.28	.03	.26	.18	.14	.15	2.30	.16	3.88	1.06
		B		1.84	1.79	2.80	.96	.14	.37	34	.07	.25	.12	.11	.10	1.20	.16	3.52	1.29
		C		2.69	2.78	4.88	1.47	.09	.36	.31	.05	.23	.39	.27	.04	1.52	.14	2.43	.67
	Coefficient of variability	A		6.7	5.5	16.2	5.3	52.9	50.4	27.5	25.0	36.6	42.9	50.0	45.5	32.3	10.5	15.9	16.1
		B		4.7	6.0	19.0	8.0	31.8	28.9	32.6	77.8	33.3	48.0	64.7	71.4	49.8	9.6	17.1	16.51
		C		7.1	8.6	37.1	11.8	27.3	38.7	34.8	55.5	44.2	72.2	77.1	26.7	43.6	8.8	15.8	11.1

TABLE 6.—*Composition and properties of colloidal materials isolated from soils of the Cecil series*

Profile No.	Location of sample	Horizon	Depth	SiO_2	Al_2O_3	Fe_2O_3	Combined H_2O	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	MnO	Organic matter	Molecular ratio, $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Base exchange capacity per 100 grams	H_2O vapor adsorbed per 100 grams
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Milliequivalents*	*Grams*
25	Goochland County, Va.	A	0– 8	42.13	34.80	8.92	11.55	0.12	0.78	0.80	0.11	0.90	0.05	0.14	0.02	6.48	1.77	9.0	4.4
		B	12– 30	38.10	35.73	11.46	12.80	.05	.52	.46	.06	1.06	.06	.06	.04	.57	1.50	8.3	6.0
		C	60– 60+	38.01	33.85	13.50	12.40	.08	.56	.42	.05	1.38	.07	.10	.05	.57	1.51	7.6	5.7
26	Rockingham County, Va.	A	4– 10	39.52	36.54	12.33	13.52	.20	------	1.03	.02	.78	.14	------	.04	5.19	1.51	8.0	3.8
		B	16– 38	38.46	35.73	11.93	12.86	.15	.24	.64	.02	.88	.03	------	.03	.38	1.50	6.9	4.5
		C	70– 70+	37.39	34.81	13.27	12.97	.04	.21	.42	.05	.75	.12	------	.07	1.12	1.46	5.8	4.3
27	Davie County, N. C.	A	1– 8	42.38	34.57	8.77	12.13	.07	.42	.73	.02	.81	.31	------	.09	3.95	1.78	13.7	4.7
		B	20– 50	39.53	34.11	12.31	13.01	.31	.50	.36	.01	.79	.18	------	.02	.76	1.59	9.6	5.0
		C	50– 50+	39.08	33.91	13.11	12.55	.31	.51	1.00	.02	.72	.20	------	.05	1.50	1.55	10.5	4.9
28	Rutherford County, N. C.	A	0– 5	34.49	36.81	11.25	14.43	.22	.56	.35	.06	1.01	.26	.20	.09	4.26	1.33	9.4	3.6
		B	5– 36	32.02	36.98	14.70	13.15	.25	.13	.18	.13	1.02	.12	.12	.06	1.11	1.18	5.6	3.3
		C	72– 96	28.84	40.05	11.00	16.60	.23	.14	.18	.09	1.09	.79	.11	.14	.86	1.03	7.0	4.4
29	----do----------	B	6– 40	33.46	36.91	14.97	12.50	.02	.23	.18	.08	.96	.02	.20	.04	1.35	1.22	4.9	4.1
30	Clarke County, Ga.	A	1– 5	34.78	38.16	9.64	14.59	.21	.13	1.04	.02	1.10	.18	------	.23	4.82	1.33	10.7	4.7
		B	5– 60	33.26	38.24	11.82	14.71	.14	.54	.51	.03	.90	.10	.12	.10	.84	1.35	7.3	4.7
		C	110–130	34.02	34.71	15.32	13.51	.20	.51	.37	.05	1.10	.25	.13	.11	1.34	1.29	7.2	4.5
31	De Kalb County, Ga.	B	20– 28	35.04	37.86	10.65	14.06	.25	.79	.30	.02	.73	.06	.18	.05	.68	1.33	8.2	5.3
32	Wilkes County, Ga.	B	12– 25	38.67	36.52	10.13	13.53	.23	.41	.22	.06	.45	.05	.12	.05	.88	1.52	7.5	3.6
33	----do----------	A	0– 9	34.73	36.89	11.27	14.75	.31	.41	.41	.10	.63	.25	.06	.15	2.25	1.34	18.0	5.2
		B	9– 36	32.30	38.84	10.17	16.80	.35	.23	.35	.01	.54	.11	.02	.14	1.44	1.20	12.5	3.8
34	Oconee County, Ga.	B	18– 28	36.14	36.96	10.34	14.31	.20	.30	.41	.01	.68	.05	.13	.02	.43	1.41	6.9	3.9
35	Henry County, Ga.	B	18– 30	32.68	40.25	10.80	14.70	.29	.30	.20	.02	.77	.11	.24	.03	.80	1.18	6.8	4.1
36	Fayette County, Ga.	B	8– 15	36.09	38.42	8.54	15.24	.19	.67	.28	.12	.60	.08	.19	.05	.86	1.39	11.6	5.7
37	Butts County, Ga.	B	10– 20	35.15	35.88	13.41	14.65	.06	.11	.52	.12	.91	.05	.08	.06	.64	1.34	8.0	3.7
38	Meriwether County, Ga.	B	15– 25	36.51	39.30	8.27	14.70	.12	.10	.39	.15	.57	.07	.07	.04	.83	1.39	9.1	4.6
39	Troup County, Ga.	A	2– 6	36.77	37.54	8.76	14.56	.25	.36	1.00	.02	1.32	.22	------	.17	6.62	1.42	10.0	4.3
		B	20– 35	36.08	34.68	14.85	12.84	.02	.10	.45	.15	.56	.08	.08	.04	.77	1.39	6.6	3.1
		C	75– 90	39.81	36.65	10.75	12.62	.07	.04	.64	.02	.60	.14	------	.03	1.36	1.55	5.7	3.4
40	----do----------	B	10– 42	37.76	33.43	14.04	12.82	.02	.05	.19	.13	.74	.02	.27	.06	2.61	1.51	6.7	3.6
		C	91–180	38.24	34.60	13.82	12.57	.20	.13	.53	.02	.95	.09	------	.05	1.30	1.49	6.6	4.0
41	Chambers County, Ala.	A	0– 7	35.18	35.80	12.84	13.24	.29	.45	.30	.05	1.00	.25	.10	.17	7.35	1.12	14.0	3.8
		B	8– 24	34.25	34.47	15.20	13.84	.08	.18	.30	.07	1.15	.04	.39	.10	1.93	1.31	8.1	4.1
		C	25– 59	36.09	34.12	14.85	12.57	.02	.07	.37	.17	.76	.04	.35	.20	1.91	1.40	10.3	4.5

TABLE 6.—*Composition and properties of colloidal materials isolated from soils of the Cecil series*—Continued

Profile No.	Location of sample	Horizon	Depth	SiO_2	Al_2O_3	Fe_2O_3	Combined H_2O	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	MnO	Organic matter	Molecular ratio, $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Base exchange capacity per 100 grams	H_2O vapor adsorbed per 100 grams
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Milliequivalents*	*Grams*
	Mean	A		37.50	36.39	10.47	13.60	.21	.44	.71	.05	.94	.21	.13	.12	5.11	1.45	11.6	4.3
		B		35.62	36.72	11.98	13.91	.16	.32	.35	.07	.78	.07	.15	.06	1.00	1.37	7.9	4.3
		C		36.43	35.34	13.20	13.22	.14	.27	.49	.07	.92	.21	.17	.09	1.26	1.41	7.6	4.4
	Standard deviation	A		3.08	1.17	1.54	1.14	.07	.18	.29	.03	.20	.08	.05	.07	1.56	.21	3.14	.51
		B		2.31	1.89	2.03	1.13	.10	.21	.13	.05	.19	.04	.09	.03	.55	.12	1.89	.80
		C		3.33	1.96	1.52	1.31	.09	.20	.23	.05	.24	.23	.10	.05	.39	.16	1.76	.60
	Coefficient of variability	A		8.2	3.23	14.7	8.4	33.3	40.9	40.8	60.0	21.3	38.1	38.5	58.3	30.5	14.5	27.1	11.8
		B		6.5	5.14	16.9	8.2	62.5	65.6	37.1	71.4	24.3	57.1	60.0	50.0	55.0	8.76	23.9	18.6
		C		9.1	5.56	11.5	9.9	64.3	74.1	46.7	71.4	26.1	109.5	58.8	55.5	30.9	11.3	23.1	13.6

GENERAL RELATIONS BETWEEN THE PROFILES

The data presented in Tables 4, 5, and 6 show a marked constancy of the colloids derived from the various samples of each series, together with an equally marked divergence between the different series. This constancy is particularly evident with respect to the relative quantities of silica, alumina, iron oxide, and water. This feature of the data will be discussed in more detail later. It is desired here to emphasize the striking similarity of the profiles of each series. The variations in the character of the colloidal material which exist in respect to the three horizons of the profiles of a soil series are slight; nevertheless they are consistent.

Table 4 shows certain differences between the compositions of the Miami colloids within a profile. The data reported show that with but few exceptions there is a regular variation in the percentage of all the constituents. The monovalent and divalent bases except sodium, in which case the quantities are small and the analytical error comparatively large, all increase with depth whereas nearly all the other constituents decrease with depth. Denison (*6*) points out a similar variation in the base content of the colloids from other soil profiles derived from glacial material.

The work of McCool (*11*) with certain Michigan soil profiles shows in some cases significant differences in the character of the colloids from different horizons. The data of Anderson and Byers (*1*) show enormous differences between the different horizons of certain podsol soil profiles. The variations in the iron oxide in respect to the three horizons are very consistent for all profiles, indicating a translocation of this constituent from the A horizon to the B horizon. Base exchange and water adsorption capacities show the colloids of the B horizon to be more active than those of the A or C horizons. These variations, though slight in all constituents except the organic matter and calcium, are, however, consistent and more or less uniform in all profiles. The organic matter is unusually well confined to the A horizon in all profiles except No. 9. The content of sulphur, phosphorus, and manganese parallel fairly well the organic matter.

The data in Table 5 for the colloidal material of the Chester soil profiles show differences in some of the constituents in respect to the horizons. The percentages of silica, in contrast with the Miami profiles, are, with one exception, highest in the B horizon, There is some variation in the alumina, iron, and combined water in all profiles. These variations differ in magnitude and are, therefore, not consistent. However, they all follow the order indicated by the means of the horizons. The percentages of monovalent and divalent base constituents with few exceptions decrease with depth. The variations in the organic matter, sulphur, phosphorus, and manganese oxides are not so consistent in the Chester profiles as they are in the Miami though they occur in the same general order. Profiles 16 and 20 of the Chester series show an accumulation of organic matter, sulphur trioxide, and phosphorus pentoxide in the C horizon. The base exchange capacity indicates a more active colloid in the A horizons, and the water adsorbed indicates a slightly more active colloid material in the B horizons of most of the profiles of the Chester series.

Table 6 shows that the colloidal material of the Cecil soil profile is more constant with respect to all constituents, except organic matter and compounds directly associated with it, than other profiles. This is noted especially in the case of profiles 26, 27, 30, and 39. Denison (*6*) reports similar data for a Cecil profile from North Carolina. When the great depth of the C horizons of the Cecil profiles is considered the total quantity of these constituents so represented is very great.

As may be seen from Tables 1, 2, and 3 the hydrogen-ion concentration with only one exeception is on the acid side in all horizons and shows little, if any, regular variation with depth except in the case of the C horizons of the Miami series in which the hydrogen-ion concentration is about that of calcium carbonate. The quantity of colloidal material is as a rule much greater in the B horizon than it is in the A or C horizons; this difference is much more pronounced in the Cecil series than it is in the Miami or Chester.

As may be seen from the foregoing discussion, the soil profiles of a given soil series are similar. The profiles of the three series here presented and those of the Leonardtown (*10*) are very dissimilar with respect to their chief constituents, but in certain features they resemble each other. In these soil series, with few exceptions, the quantity of organic matter, phosphorus, and sulphur is greatest in the A horizon. However, these constituents seem to accumulate slightly more in the C horizons than in the B horizons of the Chester and Cecil soil series, especially the Cecil. In general, the quantity of titanium oxide in the colloid of one soil series is about the same as it is in another. It varies within the profiles in no regular order except in the Miami series in which the quantities show a slight decrease with depth. However, the variations of certain constituents within a profile are very dissimilar in the different series. The silica increases with depth in most of the Chester profiles, whereas the reverse is true for the Miami and Cecil series. The active base constitutents, calcium, magnesium, potassium, and sodium, vary in the Miami profiles in the reverse order to their variation in the profiles of the Chester and Cecil. The means for iron oxide, as given in Tables 4, 5, and 6, show this constituent to be higher in the lower horizons than in the surface soils in all three series, but the quantity of this constituent differs widely in the different series. An accumulation of iron oxide in the B horizon is indicated in the Miami and Chester series. The alumina, although varying in quantity within the series, does not show any distinct variation with depth. Such variations as are noted seem to follow no regular order.

Although the foregoing discussion, together with the tables, shows clearly the general similarity of the different profiles of a single series and a marked variation between the different series, the extent to which variation within a single horizon occurs is not clearly indicated. This is, perhaps, best revealed by calculation of the standard deviation and coefficient of variability.[3]

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[3] In calculating these values the following formulas were used: Standard deviation, $\sigma=\sqrt{\frac{\Sigma d^2}{N}}$, and coefficient of varibility, $C=\frac{\sigma}{M}\times 100$. D represents the deviation of each determination from the mean (M) of the whole number of determinations (N). A mathematical treatment of this topic by H. L. Rietz is to be found as an appendix in Principles of Breeding, by Davenport (*5*).

THE MEAN VARIATIONS

Since 90, 95, and 98 per cent of the Miami, Chester, and Cecil colloids, respectively, are composed of the four major constituents silica, alumina, iron oxide, and their combined water, the constancy of these constituents determines the constancy of the bulk of the colloidal material. In general, the coefficient of variability, that is, the percentage of the standard deviation, is much smaller for these major constituents than for those making up a minor part of the whole. These values are given in Tables 4, 5, and 6 for each soil series and are collected for direct comparison in Table 7. The coefficients of variability for the four major constituents of the Leonardtown, Miami, Chester, and Cecil series average 4, 5½, 11, and 9, respectively. The water of combination of the Miami colloids is the smallest of the four major constituents and varies most, though its coefficient of variability exceeds 10 in only one instance. In the colloids of the other two soil series the iron is the most variable of the major constituents, and is also the only constituent that has a variation greater than 10. The colloidal material of the Miami silt loam shows very much the same degree of constancy in respect to the four major constituents (silica, alumina, iron oxide, and combined water), and silica-sesquioxide ratio, base-exchange capacity, and water adsorbed, as does the colloidal material of the Leonardtown silt loam, whereas the colloidal material of the Chester and Cecil soil series shows a slightly less degree of constancy.

TABLE 7.—*Coefficient of variabilities for chemical constituents and properties for the colloids of four soil series*

Soil series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	H_2O	CaO	MgO	K_2O	Na_2O
Miami	A	3.1	3.5	7.8	12.6	31.5	16.7	13.8	30.4
	B	.8	1.9	4.5	7.8	20.2	10.7	21.6	40.0
	C	4.3	4.1	6.5	9.4	71.0	5.4	6.7	25.0
Chester	A	6.7	5.5	16.2	5.3	52.9	50.4	27.5	25.0
	B	4.7	6.0	19.0	8.0	31.8	28.9	32.6	77.8
	C	7.1	8.6	37.1	11.8	27.3	38.7	34.8	55.5
Cecil	A	8.2	3.2	14.7	8.4	33.3	40.9	40.8	60.0
	B	6.5	5.1	16.9	8.2	62.5	65.6	37.1	71.4
	C	9.1	5.6	11.5	9.9	64.3	74.1	46.7	71.4
Leonardtown	A	3.1	3.7	6.7	5.7	30.8	12.6	4.2	37.1
	B	.9	1.3	3.5	6.4	33.3	12.8	11.8	27.3

Soil series	Horizon	TiO_2	P_2O_5	SO_3	MnO	Organic matter	$\frac{SiO_2}{R_2O_3}$	Base exchange	H_2O adsorbed
Miami	A	13.3	24.1	25.0	20.0	18.3	5.5	14.8	18.5
	B	15.3	23.5	40.0	27.3	60.3	2.4	8.2	6.5
	C	11.5	10.5	23.1	25.0	22.5	2.1	15.2	15.8
Chester	A	36.6	42.9	50.0	45.5	32.3	10.5	15.9	16.1
	B	33.3	48.0	64.7	71.4	49.8	9.6	17.1	16.5
	C	44.2	72.2	77.1	26.7	43.6	8.8	15.8	11.1
Cecil	A	21.3	38.1	38.5	58.3	30.5	14.5	27.1	11.8
	B	24.3	57.1	60.0	50.0	55.0	8.7	23.9	18.6
	C	26.1	109.5	60.6	55.5	30.9	11.3	23.1	13.6
Leonardtown	A	10.0	46.9	48.0	33.3	32.5	5.0	13.6	3.8
	B	6.0	27.8	46.2	40.0	36.3	2.0	6.8	3.5

The coefficients of variability of the monovalent and divalent bases shown in Table 7 are much larger than the major constituents. That such should be the case is to be expected, as the fraction of the whole represented by these four constituents is small, and unavoidable analytical errors therefore largely affect the coefficient. It is also true that these materials are approaching the limit of complete extraction in the process of rock decomposition and will be subject to great variation due to differences in the accessibility of the material to soil-forming agencies. This variation is particularly marked in the Cecil series in which the sum of the averages of these four constituents is only about 1½ per cent of the total material of the A horizon and less than 1 per cent in the B and C horizons. However, this does not explain the wide variation of the calcium in the colloids isolated from the C horizon of the Miami series. The calcium oxide of the colloids in the C horizon averages 3.14 per cent and has a coefficient of variability of 71. This is to be expected, since the parent material is calcareous glacial till and the top of the C horizon is the transitional zone in respect to the calcium carbonate. Therefore, irregularities in the depth to which it was sampled would produce wide variation in the percentages of calcium. This is evidently true for the profiles reported in Table 4 as may be seen by comparing the high percentages of calcium oxide and the unusual depths of the C horizons of profiles 2 and 9 with the corresponding values in the other profiles.

The constituents of a soil colloid which vary about as much within a soil series as they do in different series are obviously of no value in distinguishing one soil series from another. This is somewhat the case with the organic matter, phosphorus, and sulphur in the series investigated, although in the Miami series the organic matter is unusually well confined to the A horizon in all profiles except No. 9. The titanium content of all the series shows a reasonably low coefficient of variability. Nevertheless, this constituent serves but little to differentiate one soil series from another since the quantities present differ very little in different soil series. It is to be emphasized that those constituents which vary widely between different series and are rather constant within a series, are most valuable for characterizing the colloidal material of a soil series. When the causes for the variations in the character of the colloidal material of a soil series, such as variations in temperature and rainfall over the area and the heterogeneity of its parent material, are considered, it might be said that the data herein presented show a remarkable constancy for this material in these rather extensive soil series.

Table 8 shows the relative quantities representing the mean values for chemical constituents and properties of colloids of four soil series.

TABLE 8.—*Relative quantities representing the mean values for chemical constituents and properties of colloids of four soil series*

[The largest value of each constituent is represented as 100 per cent]

Soil series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	H_2O	CaO	MgO	K_2O	Na_2O
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Miami	A	100.0	69.0	63.6	59.1	100	66	60	66
	B	96.2	68.2	77.7	56.8	97	83	77	43
	C	92.9	63.6	70.5	48.4	[1] 413	100	100	69
Chester	A	73.3	86.2	94.0	92.5	67	52	22	34
	B	77.9	81.7	100.0	86.1	58	40	23	26
	C	76.5	88.0	89.5	89.9	43	29	20	26
Cecil	A	75.3	99.1	71.2	97.8	28	14	16	14
	B	71.6	100.0	81.4	100.0	21	10	8	20
	C	73.2	96.3	89.7	95.0	18	9	11	20
Leonardtown	A	86.7	77.8	80.4	85.6	51	28	31	100
	B	86.6	75.3	92.5	83.8	39	27	28	94

Soil series	Horizon	TiO_2	P_2O_5	SO_3	MnO	Organic matter	$\frac{SiO_2}{R_2O_3}$	Base exchange	H_2O adsorbed
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Miami	A	80	54	40	61	78	100	84	72
	B	69	31	30	33	26	93	100	100
	C	65	35	26	24	18	97	94	80
Chester	A	76	78	56	100	93	57	63	73
	B	80	46	34	42	31	62	53	87
	C	53	100	70	45	46	59	40	68
Cecil	A	100	39	26	36	67	54	30	48
	B	83	13	30	18	13	51	20	48
	C	98	39	34	27	16	52	20	49
Leonardtown	A	96	59	100	18	100	75	51	61
	B	89	33	52	12	37	75	61	78

[1] This determination is not represented by 100 since the calcium determination in the C horizon is largely colloidal calcium carbonate and therefore not comparable to the other calcium determinations.

DIFFERENCES IN COMPOSITION OF COLLOIDS FROM SOILS OF THE DIFFERENT SERIES

The colloids of the different soil series examined are, in general, very different. Table 8 is designed to distinctly portray these differences. In this table all the individual constituents are calculated to a common basis. The highest value of each constituent is taken as 100, and that of the others, consequently, is expressed as a definite percentage of this maximum. The mean value of each constituent is thus compared with corresponding mean values in all the horizons of the four soil series.

The four major constituents form a very large part, from 90 to 98 per cent, of the total colloids. Consequently, the especially significant differences between the colloids should be revealed by variations of these factors. Examination of Table 8 shows that these major constituents vary widely in the different soil series.

In previous publications (*2*, *18*) attention has been called to the silica-sesquioxide ratio as an index to the general characteristics of soils. If these series are arranged according to this ratio the order becomes Miami, Leonardtown, Chester, and Cecil in all horizons. This order is maintained for the four major constituents, if the reciprocal character of the relation is kept in mind, except for the interchange of position of the Cecil and Chester series in the A and B horizons with respect to the iron oxide and in the A horizon with respect to silica. The combined water varies inversely with the silica-sesquioxide ratio. This would seem to indicate that the quantity is dependent on the alumina and iron oxide present.

The silica-sesquioxide ratio is not followed so closely by the monovalent and divalent bases. Only in the case of potassium is the order what would be expected from the ratio, that is, decrease as the ratio decreases. In soils of the Leonardtown series the quantities of magnesium and calcium are lower than their silica-sesquioxide ratio would warrant, judging from the mean of that shown by the different series. The sodium content also is not in accord with the ratio, but not much stress can be placed on this fact because of the exceedingly small amount present in any case. The same parallel relationship with the silica-sesquioxide ratio is to be observed with the base-exchange capacity and water-vapor adsorption. These properties follow the order of calcium and magnesium, and compare most closely with the order of the calcium content. Although it is clear from the foregoing discussion that no one relation is adequate for differentiation of soil colloids, as represented by the four soil series considered, it is nevertheless true that, in general, the silica-sesquioxide ratio best serves this purpose. If it is used as an index of colloidal characteristics, then the Miami, Leonardtown, Chester, and Cecil soil series bear a numerical ratio to each other corresponding to 100: 75: 60: 50, as expressed by the silica-sesquioxide ratio shown in Table 8. This relation as expressed by differences in base exchange capacity changes both the numerical differences and the order. The same statement holds for the calcium and magnesium oxides. The quantities of organic matter, phosphorus pentoxide, sulphur trioxide, and titanium oxide are so variable within each series that no general conclusions regarding the colloid characteristics are deducted from them.

The data presented for the four soil series considered show that although each has its own range of variation in colloid composition, the differences between series are sufficiently wide to sharply differentiate them. This result is to be expected when the soils are derived from different soil materials, developed under different climatic conditions, and differ in degree of maturity. The Miami series differs in these respects most widely from the other three, and its colloid composition is correspondingly different. On the contrary, the Chester, Leonardtown, and Cecil series are not so divergent in source and yet are sufficiently different, when studied under field conditions, to be differentiated one from the other. The character of their colloids likewise shows marked variation. This degree of variation is not to be expected between the colloids of all series, and it is, perhaps, obvious that gradations should occur between soil series with respect to the composition of their colloids even as there are soil areas difficult of satisfactory classification. This difficulty is illustrated in Table 9.

TABLE 9.—*Average composition of colloids from various Chester soil profiles in comparison with the composition of the colloids of a soil profile varying from the Chester type*

Value	Horizon	SiO_2	Al_2O_3	Fe_2O_3	Combined H_2O	CaO	MgO	K_2O	Na_2O	$\frac{SiO_2}{R_2O_3}$	Base exchange capacity per 100 grams	H_2O vapor adsorbed per 100 grams
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Milliequivalents*	*Grams*
1[1]	A	36.47	31.68	13.83	12.86	0.51	1.65	1.02	0.12	1.53	24.4	6.6
	B	38.80	29.98	14.71	11.98	.44	1.28	1.04	.09	1.66	20.6	7.8
	C	38.06	32.33	13.16	12.51	.33	.93	.89	.09	1.59	15.3	6.1
2[2]	A	30.44	30.45	17.40	11.62	.66	4.17	1.40	.10	1.24	29.0	8.0
	B	37.95	26.17	17.48	9.87	.30	3.21	1.88	.10	1.69	27.2	9.7
	C	42.78	29.03	10.53	10.62	.62	3.32	1.50	.58	2.03	29.2	7.7

[1] Average values for chemical character of Chester colloids from Table 5.
[2] Values for colloids of a Chester soil profile deviating from typical characteristics.

In Table 9 are given the inorganic composition, base-exchange capacity, and water-vapor adsorption, of the colloids derived from a profile of soil collected by S. O. Perkins of this bureau near Longwood, Pa. The area is typically Chester and the sample in question seemed normal in character except in the color of the A horizon. The soil material from which it is derived is also somewhat different from that of the ordinary Chester areas. For comparison, there is also given the corresponding average values for the Chester colloids given in Table 5. The B horizon is normal for the Chester profile, but peculiar differences occur in both the A and C horizons. The silica-sesquioxide ratio is lower in the A horizon and higher in the C horizon than in any other Chester sample examined. This would seem to indicate an abnormally highly weathered A horizon and an unusual lack of maturity in the C horizon. The rather high and uniform content of monovalent and divalent bases indicate uniformly a lack of maturity in all horizons. The water of combination, which should correspond to the silica-sesquioxide ratio, is much too low in the A horizon. Although it is true that the Chester colloids offer variations from the mean, no other single colloid examined shows such a wide range as this one. The sample most closely approaching the profile in question is profile No. 13 in Table 5, which is from the same county, and approximately 20 miles away.

A general conclusion which may be derived from the data presented in this study is that the colloids of a given soil series are remarkably constant in character and essentially different from those of even closely related series. It would be obviously of great advantage to soil science to so relate laboratory examination to the field characteristics of soils that the identification of a series by laboratory investigation would be possible. Such a relationship would aid in the differentiation of series and assist in the classification of indeterminate areas and in the identification of doubtful samples. Unfortunately the present data are not adequate for such purpose, yet hope of ultimate success is offered when similar data for other soil series shall have been accumulated.

SUMMARY

An investigation is made of the extent to which the colloidal material is characteristic of the soil series.

Complete chemical analyses of the colloids isolated from a number of samples of profiles from each of the Miami, Chester, and Cecil soil series are presented, together with their base-exchange capacity and water-vapor adsorption.

A description is given of each soil profile, its location, hydrogen-ion concentration, and colloidal content.

The variations within the profile characteristic of the soil series are pointed out. The relative constancy in composition of the colloids of each series is calculated and discussed. A comparison is made between the colloids from the different soil series.

The character of the colloidal material from a soil profile not typical of its series is compared with the mean of that series.

The slight variations occurring within the profiles of each soil series are very similar; furthermore, the manner of variation within the profiles of one series differs from that of another.

The colloids of the various profiles of a soil series are remarkably similar in character and are essentially different from those of even closely related series.

LITERATURE CITED

(1) Anderson, M. S., and Byers, H. G.
1930. character of the colloidal materials in the profiles of certain major soil groups. U. S. Dept. Agr. Tech. Bul. 228, p. 24.

(2) ——— and Mattson, S.
1926. properties of the colloidal soil material. U. S. Dept. Agr. Bul. 1452, 47 p., illus.

(3) Baldwin, M.
1928. the gray-brown podsolic soils of the eastern united states. First Internatl. Cong. Soil Sci. Proc. and Papers 4: 276–282.

(4) Bradfield, R.
1925. the chemical nature of colloidal clay. Jour. Amer. Soc. Agron. 17: 253–270, illus.

(5) Davenport, E.
1907. principles of breeding . . . 727 p., illus., Boston, New York [etc.].

(6) Denison, I. A.
1930. the chemical composition of colloidal material isolated from the horizons of various soil profiles. Jour. Agr. Research 40: 469–483.

(7) Gile, P. L., Middleton, H. E., Robinson, W. O., Fry, W. H., and Anderson, M. S.
1924. estimation of colloidal material in soils by adsorption. U. S. Dept. Agr. Bul. 1193, 42 p.

(8) Hall, A. D., and Russell, E. J.
1911. soil surveys and soil analyses. Jour. Agr. Sci. 4: 182–223.

(9) Hillebrand, W. F.
1919. the analysis of silicate and carbonate rocks. U. S. Geol. Survey Bul. 700, 285 p., illus.

(10) Holmes, R. S.
1928. variations of the colloidal material in typical areas of the leonardtown silt loam. Jour. Agr. Research 36: 459–470.

(11) McCool, M. M.
1927. results of some physical and chemical studies on soil colloids. Jour. Amer. Soc. Agron. 19: 289–297.

(12) MARBUT, C. F.
1921. THE CONTRIBUTION OF SOIL SURVEYS TO SOIL SCIENCE. Soc. Promotion Agri. Sci. Proc. Ann. Meeting 41: 116–142, illus.
(13) ———
1922. SOIL CLASSIFICATION. Amer. Assoc. Soil Survey Workers Bul. 3, p. 24–32. [Mimeographed.]
(14) ROBINSON, G. W.
1917. STUDIES ON THE PALAEOZOIC SOILS OF NORTH WALES. Jour. Agr. Sci. [England] 8: 338–384, illus.
(15) ROBINSON, W. O.
1922. THE ABSORPTION OF WATER VAPOR BY SOIL COLLOIDS. Jour. Phys. Chem. 26: 647–653.
(16) ———
1927. THE DETERMINATION OF ORGANIC MATTER IN SOILS BY MEANS OF HYDROGEN PEROXIDE. Jour. Agr. Research 34: 339–356.
(17) ———
1930. METHOD AND PROCEDURE OF SOIL ANALYSIS USED IN THE DIVISION OF SOIL CHEMISTRY AND PHYSICS. U. S. Dept. Agr. Cir. 139, 20 p.
(18) ——— and HOLMES, R. S.
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U. S. Dept. Agr. Bul. 1311, 42 p.
(19) STEPHENSON, R. E.
1929. COLLOIDAL PROPERTIES OF WILLAMETTE VALLEY SOILS. Soil Sci. 28: 235–247.

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TECHNICAL BULLETIN No. 230 MARCH, 1931

MACROCENTRUS GIFUENSIS ASHMEAD, A POLYEMBRYONIC BRACONID PARASITE IN THE EUROPEAN CORN BORER

BY

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Entomologist
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Bureau of Entomology

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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By H. L. PARKER

Entomologist, Division of Cereal and Forage Insects, Bureau of Entomology[1]

CONTENTS

	Page
Discovery in Europe and identity of the species	1
Geographic distribution and host relations	2
History of polyembryony in Hymenoptera	2
Technic followed	6
Explanation of symbols used in the illustrations	7
Description of *Macrocentrus gifuensis*	8
The adult	8
The egg	9
The larva	9
The prepupa and pupa	23
The cocoon	23
Biology	24
Emergence	24
Light reactions	24
Feeding	24
Oogenesis	24
Copulation	24
Oviposition	25
Segmentation of the egg	29
Growth and development of the egg	30
Pseudogerms	36
Cyst formation	38
Larval habits	38
Effect of parasite on host larva	42
Spinning and pupation	43
Biology—Continued.	
Average size of colony and proportion of sexes	44
Parthenogenesis	46
Consideration of the zones in which *Macrocentrus gifuensis* occurs	47
Physical characteristics	47
Climatic characteristics	48
Seasonal history	49
Seasonal history of the host	49
Seasonal history of the parasite	49
Experimental data	51
Laboratory breeding experiments	52
Mortality in rearing of field material	52
Summary of duration of various stages	53
Rapidity of spring development	53
Mortality in the prepupal and pupal stages	55
Cold storage of overwintering host larvae containing parasites	55
Cold storage of cocoons	56
Macrocentrus gifuensis as a controlling factor of *Pyrausta nubilalis*	56
Limiting factors	57
Recommendations	57
Summary	58
Literature cited	61

DISCOVERY IN EUROPE AND IDENTITY OF THE SPECIES

Macrocentrus gifuensis Ashm.,[2] a primary parasite in the larva of the European corn borer (*Pyrausta nubilalis* Hübn.), was found in common mugwort, *Artemisia vulgaris* L. (*29*),[3] in the Armorican zone of western France by W. Gamkrelidze, of this laboratory, while on an exploration trip during the summer of 1925.

[1] The work reported in this bulletin was done at the European Parasite Laboratory of the Bureau of Entomology at Hyères, Var, France, from April, 1927, to October, 1929.

The writer expresses his gratitude to Paul Marchal for examining and criticizing the microscopic preparations and drawings; to C. F. W. Muesebeck and A. B. Gahan for help with the identity and description of this species; to Esther Hart for her drawings of the adult and cocoons; to W. R. Walton, W. R. Thompson, and E. Rabaud for help with the manuscript; to V. Malama for the photomicrographs; and to A. M. Vance, H. D. Smith, and Th. Malama for help in various ways.

[2] Family Braconidae, order Hymenoptera, class Insecta.

[3] Italic numbers in parentheses refer to Literature Cited, p. 61.

24081—31——1

Further study by the writer soon revealed the fact that this species was an important primary parasite, and exportations to the United States for colonization were begun the following year.

At first it was believed that this species was *M. abdominalis* Fab., and in an earlier publication (*29*) it was so designated. The writer has not examined the type of *M. abdominalis*, but A. B. Gahan has compared specimens from *P. nubilalis* with the type of *M. gifuensis* and believes that they are the same species, while he considers *M. abdominalis* to be a distinct species.

GEOGRAPHIC DISTRIBUTION AND HOST RELATIONS

This species has been reared by the writer from host larvae taken from Artemisia in the Sequanian (south), Armorican, and Central zones in France, and from corn in the Danaprisian (north) zone in Russia. W. B. Cartwright has reared it in Japan from *P. nubilalis* taken in corn and hemp. Hergula (*7*) has bred from larvae taken from corn at Kraljevec and Bjelovár in Jugoslavia a species of Macrocentrus which he claims is identical with that bred from Tours material. It is quite likely that this is also *M. gifuensis*.

So far as is known it has not been reared from other hosts than *P. nubilalis*. It is possible, however, that *M. gifuensis* has often been misidentified as *M. abdominalis* and that, consequently, some of the biological and descriptive data in publications on *M. abdominalis* pertain in reality to *M. gifuensis*. As there is no definite proof of this condition at present, such data can not be definitely incorporated in a paper devoted exclusively to *M. gifuensis*.

HISTORY OF POLYEMBRYONY IN HYMENOPTERA

The discovery of polyembryonic development in the parasitic Hymenoptera by Paul Marchal and his subsequent studies and those of F. Silvestri are so well known and have been cited so often that it is not necessary to go into detail concerning these matters.

For the purpose of completeness, however, it is considered desirable to cite here the forms known to reproduce by polyembryony as well as those suspected of such reproduction. It is pointed out that most workers on the Hymenoptera suspect that a great many of the vast group of Encyrtidae, whose biology is as yet unknown, will be found to reproduce in this manner.

Polyembryony in the Braconidae,[4] more especially in the genus Macrocentrus, was suspected as early as 1913 by Cushman (*3*). In 1927 Voukassovitch (*30*) supposed it to exist in *M. abdominalis*, a parasite of *Psammotis hyalinalis* Hbn. Later, Thompson and Parker (*29*) held it probable that *M. gifuensis* (then erroneously called *M. abdominalis*) reproduced in this manner.

This bulletin leaves unclarified many aspects of the reproductive activities of *M. gifuensis*, such as oogenesis and the origin of the germ-cell determinant, the maturation divisions of the female pro-

[4] Fink (*5*) describes the transformation and change in shape of the egg of *M. ancylivora*, but he gives no data on the segmentation or the structure of the germs and embryonic membranes. After a careful study of Fink's remarks on the superparasitism, etc., in this species the writer considers it possible that there is polyembryony in *M. ancylivora*. In all events the matter should be investigated more closely.

nucleus, the conjugation of the male and female pronuclei, the conjugation of the germ-cell determinant, and early divisions of the primary cleavage nucleus.[5]

The writer holds, however, that he has demonstrated the following points: (1) The differentiation of the egg into a pregerm composed of a paranucleus (probably derived from the polar nuclei) which directs and governs the trophamnios, and germinative or true embryonic cells which give rise to embryos; (2) the division by fission of the primary germ accompanied by a division of the paranucleus to form the secondary germs, which again divide to form morulae, which demonstrate (3) polyembryony in *M. gifuensis*.

A summary of our knowledge of polyembryony among the parasitic Hymenoptera is presented in Tables 1 and 2.

---

[5] This phase of development will be made the subject of further researches.

TABLE 1.—*Parasitic Hymenoptera known to reproduce by polyembryony*

Family or superfamily	Parasite species	Authority for polyembryony in the species	Host	Number formed from one egg or issuing from one host	Brief summary of details and peculiarities of development
Chalcidoidea	Ageniaspis fuscicollis (Dalm.) Th.	Marchal (*15*)	Hyponomeutus malinellus et al.	150	Polar bodies form paranuclei which (in trophamnios) encircle germ cells at or shortly after first cleavage. Blastomeres become grouped in many distinct groups forming morulae. Morulae divide by fission. Proliferation of host tissue to form a nucleated membrane which incloses all morulae and elongates in form of a chain. No dissociation of parasite body. Develops in visceral cavity.
Do	A. fuscicollis praysincola Silvestri.	Silvestri (*25*)	Prays oleellus Fab.	10	Similar, except that paranuclei from polar bodies do not encircle germinative cells until 12-celled stage.
Do	Litomastix truncatellus Dalm.	Silvestri (*24*)	Plusia gamma L.	1,800	Segmenting egg differentiates into two distinct parts; one part from the polar bodies forms a nucleated membrane, the trophamnios, and incloses the other part, the blastomeres. These become grouped in many groups of about 6 cells, forming polymorulae. The whole mass is broken up into many polymorulae and isolated morulae and these are distributed throughout the host's body. Each morula or polymorula remains inclosed by a part of the nucleated membrane (i. e., trophamnios with its governing paranuclei). In addition to sexual larvae, asexual or monster larvae are formed which do not develop to maturity. Develops in visceral cavity.
Do	Ageniaspis testaceipes Ratzb.	Marchal (*15*)	Lithocolletis cramerella.	12–15	Advanced stages found in cyst of host tissue similar to that caused by A. fuscicollis.
Do	Copidosoma buyssoni Mayr.	Silvestri (*26, 27*)	Coleophora stefanii Joan.	41–119	Probably similar to A. fuscicollis. Paranuclei do not encircle germinative cells before 14-celled stage.
Do	Copidosoma nanellae Silv.	Silvestri (*28a*).	Recurvaria nanella Hübn.	3–11	Embryonic chains and asexual larvae observed by Silvestri.
Do	Copidosoma gelechiae How.	Leiby (*10*), Patterson (*20*).	Gnorimoschema gallaesolidaginis Ril.	165	Polar bodies form paranuclei. Blastomeres become grouped in groups of about 6 cells; trophamnios with its paranuclei incloses whole body. Parasite body dissociates into isolated morulae or polymorulae of various sizes, each remaining inclosed by part of trophamnios. Morulae divide by fission. Develops in visceral cavity.
Do	Copidosoma boucheanum Ratz.	Parker (*19*)	Gelechia pinguinella Treits.	38	Develops in visceral cavity in chains resembling those of A. fuscicollis. Asexual larvae present.
Do	Copidosoma thompsoni Merc.	----do	Nothrix senticetella Stgr.	18	Similar to C. boucheanum. Male unknown.
Do	Litomastix kriechbaumeri Mayr.	Ferrière (*4*)	Depressaria alpigenella Frey.	21–120	Chains of developing embryos observed in body cavity.
Serphoidea	Polygnotus minutus Lindm.	Marchal (*15*)	Phytophaga destructor Say.	10–12	In morula stage the peripheral cells become detached to form the paranuclei of the trophamnios. The remaining cells in the center become grouped in 5 or 6 main groups, all remaining inclosed by the trophamnios. Each group so formed gives rise to a larva. Develops in gastric sac.

Do	Platygaster vernalis Myers.	Leiby and Hill (*13*)	do	8	Two polar bodies formed, which constitute the original paranuclear masses or governing nuclei of the trophamnios. The cleavage nucleus divides four times, thus giving rise to 16 cells, each of which apparently produces an embryo-forming germ. The germs remain together surrounded by the trophamnios. Some of them may divide once by fission. Development takes place in gastric sac.
Do	Platygaster hiemalis Forbes.	Leiby and Hill (*12*)	do	1 or 2	Two polar bodies are formed which unite to form the paranucleus of the trophamnios. Cleavage nucleus gives rise to a 4-celled germ which divides in 2 daughter germs, each germ taking 2 cleavage cells. Paranucleus divides to supply each daughter germ. The 2 daughter germs separate and give rise to 2 embryos. Development takes place in visceral cavity. This species may also develop by monembryony and is considered an example of the most primitive method of polyembryonic development.
Do	Platygaster variabilis Fouts.	Leiby (*11*)	Rhopalomyia carolina.	15	Early stages not elucidated.
Braconidae	Macrocentrus gifuensis Ashm.	Parker (present bulletin).	Pyrausta nubilalis Hbn.	10	Early stages of egg segmentation and formation of pregerms seem to resemble those of A. fuscicollis; primary germ divides by fission to form 2 secondary germs. Paranucleus divides and half accompanies each germ. The paranuclear cells multiply by amitosis and via the trophamnios they eventually encircle completely the germinative center. The secondary germs again divide to form tertiary germs or morulae, which by multiplication of embryonic cells transform to embryos. General dissociation of germs; some remain grouped in bodies of 2 to 6, thus forming polygerms; many become completely isolated.

TABLE 2.—*Hymenoptera suspected of polyembryonic reproduction*

Family or superfamily	Parasite species	Authority	Host	Number issuing from one host	Facts on which supposition of polyembryony is based
Chalcidoidea	Encyrtus mayri Masi	Silvestri (*28*)	Oecophyllembius neglectus Silv.	11	Early stages of egg segmentation resemble those of E. fuscicollis.
Do	Encyrtus variicornis Nees.	Sarra (*22*)	Anarsia lineatella Zell.	28	Biological observations on numbers issuing from a single host indicate polyembryony.
Do	Copidosoma sp	Sarra (*23*)	Olethreutes variegana Hbn.	68 to 80	Do.
Do	Homalotylus flaminius Dalm.	W. R. Thompson (unpublished notes).	Coccinellid larva	12	Number in host and manner of arrangement of individual pupation cells, and sexes of adults, lead to suspicion of polyembryony.
Serphoidea	Platygaster felti Fouts	Patterson (*21*)	Walshomyia texana Felt.		Biological observations relative to sex, etc., lead to this belief.
Dryinidae	Aphelopus theliae Gahan.	Kornhauser (*9*)	Thelia bimaculata Fab.		
Bracondae	Macrocentrus abdominalis Fab.	Voukassovitch (*31*)	Psammotis hyalinalis Hbn. et al.	24 to 29	Observations on size of colonies, sexes of adults in colonies, etc., indicate that polyembryony is probable.

TECHNIC FOLLOWED

The parasitized host larvae were collected and kept for storage and rearing purposes in corrugated paper in copper cans, a system devised by Jones (*8*) for shipping and rearing. Contact moisture was supplied when necessary by plunging the cans in water.

The colonies of Macrocentrus cocoons spun in these cans were removed to glass vials for observations and supply.

Adults were kept in several sizes of lamp globes seated on a cloth base and in glass vials. Moist cotton in a glass dish was placed on the floor of each cage and wet cotton wads were attached to the underside of the screen-wire top. Food was supplied by smearing granulated honey on a small area on the wall of each cage, over which distilled water was dropped at intervals; distilled water for drinking was sprayed on the walls.

Dry incubators at 18°, 20°, and 25° C. were used in all experiments and an electric refrigerator at 4° to 8° C. was employed in the cold experiments.

For oviposition purposes it was found necessary to confine the young larvae for the reason that a larva free to move usually escaped from an attacking female without receiving a thrust. This condition, combined with the small size of the egg and the ease with which it could be lodged or concealed in the host organs, required that a larva be stung several times before an egg could be recovered, as larvae stung only once or twice seldom or never yielded an egg by simple dissection in physiological media. This confinement was accomplished by "sewing" the larva down to the cloth base of the cage with a fine wire or thread. A piece of leaf with several small holes in it was placed over the larva. A small amount of larval frass was then smeared over the upper surface of the leaf to excite the females to oviposition. In this way, as the ovipositor was thrust into the holes it would generally encounter the fixed host larva and oviposition would result. After 10 to 15 thrusts, dissection of the larva would usually yield an egg or sometimes two or three. Larvae so impaled were useless for rearing purposes, however. This technic was later improved in the following manner: Small larvae were isolated in glass tubes together with a tiny stem or cube of a food plant, such as mugwort, dock, or corn. After the larva had burrowed into it for about the length of its body, this stem with the contained larva was placed in the cage to receive oviposition. In this way it was possible to procure a considerable number of thrusts in a single larva.

The ovaries were studied by dissection and simple observation and by sectioning in paraffin both within the abdomen and removed from it.

Eggs were studied by direct microscopic observation with and without stains and by sectioning parasitized host larvae.

Parasite bodies and germs in all (recorded) stages were studied by direct observations, stained and unstained, and by sectioning both within the host and free from it.

The fixing fluids mostly employed were Bouin's, Duboscq-Brasil, Carnoy's, Carnoy and Le Brun's, and Flemming's without acetic acid. Bouin's proved to be the most satisfactory by far.

Stains used were alcohol-carmin and carmalum for entire bodies, glychemalum and eosine, trichromique de Cajal, iron hematoxylin,

orange G, and Congo red and hemalum. The most satisfactory method was to use acid glychemalum followed by eosine.

For topographical studies of the internal organs, muscles, etc., larvae were fixed in Carnoy's and kept on 95 per cent alcohol. The desired organs were then dissected out with fine needles. The histological observations and illustrations were made from specimens fixed in Bouin's and then sectioned, and stained in glychemalum and eosine. It is here pointed out that the tissues of parasitic larvae are more difficult to stain than those of nonparasitic larvae. For this purpose glychemalum proved to be an excellent stain.

EXPLANATION OF SYMBOLS USED IN THE ILLUSTRATIONS

at, antenna.
ac, anterior commissure.
an, anal opening.
ap, anterior portion.
bc, blood cell.
br, brain.
cesc, circumesophageal commissure.
ch, chorion.
cu, cuticle.
do, dorsal.
dc, dividing cell.
dl, dorsolateral.
dll, dorsolateral lobes.
dv, dorsoventral.
dvo, dorsoventral oblique.
e, embryo.
ec, embryonic cavity.
el, epithelial layer.
er, evaginated rectum.
es, esophagus.
esm, esophageal muscle.
esp, esophageal pump.
esv, esophageal valve.
esw, esophageal wall.
f, fat.
fb, fat body.
fc, fat cell.
fm, food material.
fg, frontal ganglion.
frg, fragment.
fv, food vacuole.
g, gonad.
gc, germinative cells.
gctr, germinative center.
gm, germ.
h, head.
hb, histoblast.
hi, hind-intestine.
hrt, heart.
ht, host tissue.
hy, hypodermis.
ic, imaginal cells.
id, imaginal disk.
idr, imaginal disk, reproductive organs.
il, ileo-colon.
ila, inner layer.
imda, imaginal disk, antenna.
imt, imaginal Malpighian tubes.
l, lateral.
lb, labium.
lbp, labial palpi.
lbr, labrum.
lbrp, labral processes.
ll, lateral lobes.
lm, longitudinal muscles.
lt, lateral trunk.
ly, leucocytes.
m, muscle.
mb, membrane,
md, mandible.
mf, muscle fibers.
mi, mid-intestine
mitep, epithelium of mid-intestine.
ml, middle layer.
mm, mesenchymatous material.
mo, morula.
mth, mouth.
mplp, palpi of mentum.
mt, Malpighian tubes.
mx, maxillae.
n, nerve.
nc, nuclear cavity.
nch, nerve chain.
nfc, nucleus of fat cell.
nlfc, normal fat cell.
o, opening.
oe, oenocyte.
ol, outer layer.
ov, ovary.
pc, pericardial cells.
pha, phagocytes.
plrm, polar material.
pm, peritrophic membrane.
poc, posterior commissure.
pr, press.
prn, paranucleus.
psgm, pseudogerm.
r, rectum.
rm, rectal muscle.
s, spiracle.
sc, secretory cells.
scpm, secretory cells of the peritrophic membrane.
sd, salivary duct.
seg, segmental line.
sesg, subesophageal ganglion.
sg, salivary gland.
sgd, duct of salivary glands.
sk, skin.
sm, solid material.
spc, spermatocytes.
spr, spinneret.

sp, sensory papillae.
st, stomach.
t, transverse.
th, thorax.
tm, transverse muscles.
tmf, transverse muscle fibers.
to, tentorium.
tr, trachea.
trm, trophamnios degenerated into a thin membrane.
tro, trophamnios.
u, urate cells.
ue, unstained edge.
v, vacuole.
vdo, ventrodorsal oblique.
vl, ventrolateral.
vll, ventrolateral lobes.
vt, ventral.
wmi, wall of mid-intestine.

DESCRIPTION OF MACROCENTRUS GIFUENSIS

THE ADULT

The adult (fig. 1) is described by Ashmead (*1*, *p. 191*) as follows:

Female.—Length, 4.5 mm.; ovipositor longer than the whole insect. Head black; thorax brownish yellow, the metathorax dusky or brownish; abdomen

FIGURE 1.—Adult female of *Macrocentrus gifuensis*. × 10

above brown or blackish, sometimes paler at the sutures, variable, the first, second, and third segments longitudinally striated; antennae very long, brownish yellow, becoming dusky toward apex, 40 or more jointed, the joints dusky

at apex, appearing annulated; legs, including coxae, yellow. Wings hyaline, the veins brownish, the stigma with a large dark brown blotch within.

Type.—Cat. No. 7274, U.S.N.M.

Locality.—Gifu (Y. Nawa). Two specimens.

M. gifuensis is easily distinguished from the other parasites of the corn borer by its slender, delicate form, its light-brown color, long antennae, and the slender ovipositor of the female.

OVARIES

The ovaries are of the meroistic type and are bunched in two groups, one on each side. There are usually 12 to 15 ovarian tubes in each group, though in some individuals there are as few as 8. The tubes of each group are joined together at their bases and empty into short oviducts; these unite to form a short vagina to which the blackish spermatheca and the various glands common to the Braconidae (*6*, *18*) are attached. In some cases the two oviducts are joined, superficially at least, at the base of the ovarian tubes, separating immediately below this point and coming together again into the vagina, thus forming a sort of loop. It is improbable, however, that there is a mutual lumen at this distal junction.

FIGURE 2.—Eggs of *Macrocentrus gifuensis:* A, Ovarian or newly laid egg; B, another form of the ovarian egg. The nuclei are in the early stages of segmentation (less than 5 hours old)

THE EGG

The ovarian and newly laid egg (fig. 2, A, B) measures from 0.08 to 0.12 mm. long by 0.028 to 0.056 mm. wide; it varies somewhat in shape but in general is more or less ovoid, with one end (the end directed downwards in the ovary) slightly pointed. It has a large nucleus near the center and a nucleuslike mass of dense granular material at the lower end (fig. 2, A), which is probably the germ-cell determinant or "nucleolo plasmatico" of Silvestri (*24*). The rest is densely granular material.

THE LARVA

FIRST STAGE [6]

SIZE, COLOR, AND FORM

Length of newly hatched larva, 1.5 mm.; width, 0.28 mm.; width of head, 0.298 mm.; length of mandibles, 0.0954 mm.; length of larva after feeding, 3 mm.; width, 0.43 mm. (Fig. 3, A, B.)

The color is translucent grayish white, the head concolorous with the body.

The larva of this stage is composed of a large, somewhat flattened head with protruding, distinctly delineated buccal regions and 13 well-defined body segments bearing four rows of prominent lobes resembling pseudopods.

EXTERNAL ANATOMY

The head is somewhat more heavily chitinized than the body segments, and anteriorly the fleshy mouth parts protrude as if "over-

[6] Fink (*5*) has described the first-stage larva of *M. ancylivora*. His Figure 4 resembles but little his photographs (fig. 3, H) of the first-stage larva. It would not be surprising to find that the newly hatched larva of *M. ancylivora* is very similar to that of *M. gifuensis*.

flowing" from the more solid skeleton of the head. These parts include a distinct labral region having two separate sensory papillae (fig. 3, C, *sp*) and two very prominent conical protrusions or labral processes (fig. 3, C, D, *lbrp*), each of which has five sensorial papillae; the labium (fig. 3, C, *lb*), which has two similar protrusions

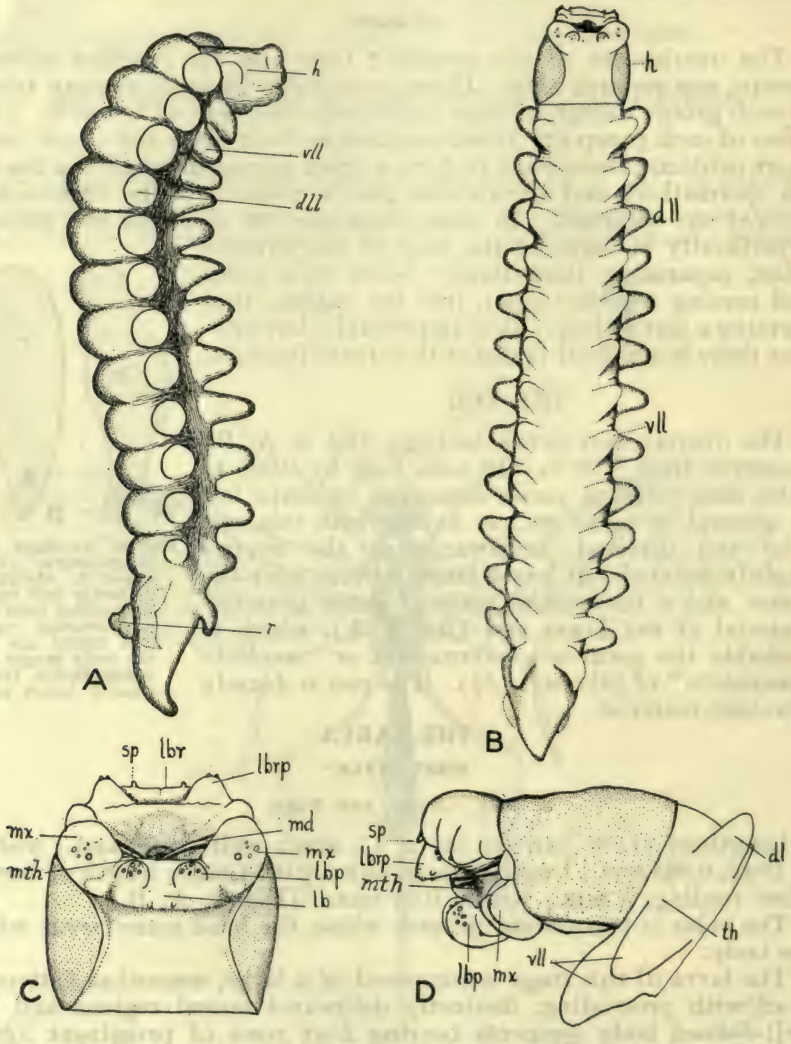

FIGURE 3.—First-stage larva of *Macrocentrus gifuensis:* A.—First-stage larva viewed in a plane extending obliquely through longitudinal axis of body and cutting vertical plane at an angle of 45°. In this position the head is somewhat foreshortened. B.—Ventral view of first-stage larva. C.—Head of first-stage larva, ventral view. D.—Same, side view

(*lbp*), each having seven pairs of sensory papillae in addition to an isolated pair located ventrally near the median line; and the maxillae (*mx*), which are clearly defined, each bearing five sensory papillae. The simple mandibles (fig. 4, A) are light brown in color, rather slender, and only slightly curved.

The body proper is approximately cylindrical, but the presence on each of Segments I to XIII of four enormous fleshy lobes gives it a rather flattened appearance bearing a superficial resemblance to certain isopods. (Fig. 3, A.) These lobes are placed along the dorsolateral and ventrolateral lines, and all pairs extend in ventrolateral and dorsolateral directions, except the ventrolateral pair on

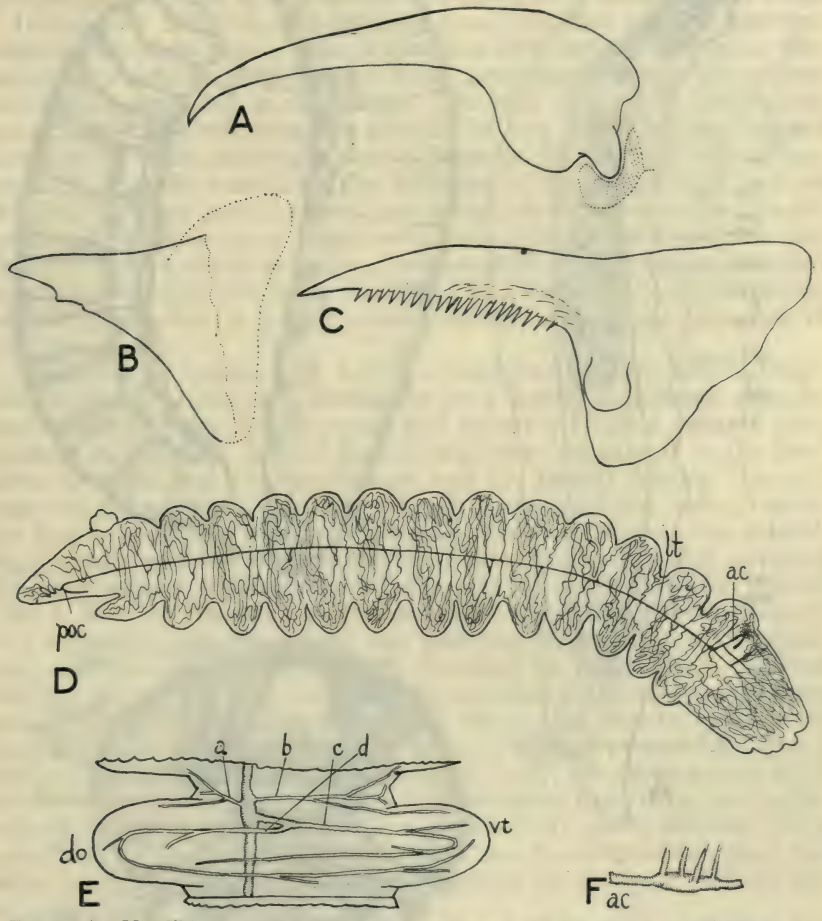

FIGURE 4.—Mandibles and tracheal system of larvae of *Macrocentrus gifuensis:* A, Mandible of first-stage larva; B, mandible of second-stage larva; C, mandible of third-stage larva; D, tracheal system of first-stage larva; E, segment of body of first-stage larva to show origin and direction of principal tracheal branches; *a* and *b* are branches extending inwardly, and *c* and *d* are branches extending outwardly; F, tracheal branches from middle of anterior commissure of first-stage larva

Segment XIII, which is curved caudad. The dorsolateral pair on Segment XIII is inconspicuous or absent in some specimens; Segment XIII is conically pointed posteriorly and bears dorsally the evaginated rectum. There are no tegumentary spines or setae.

INTERNAL ANATOMY

The digestive tract commences at the mouth; the esophageal pump or pharynx is located immediately posterior to the mouth and the

esophagus connects this organ with the mid-intestine into which it empties in Segment II. At this point there is an esophageal valve which prevents the regurgitation of the food. (Fig. 5, A, *esv.*) The

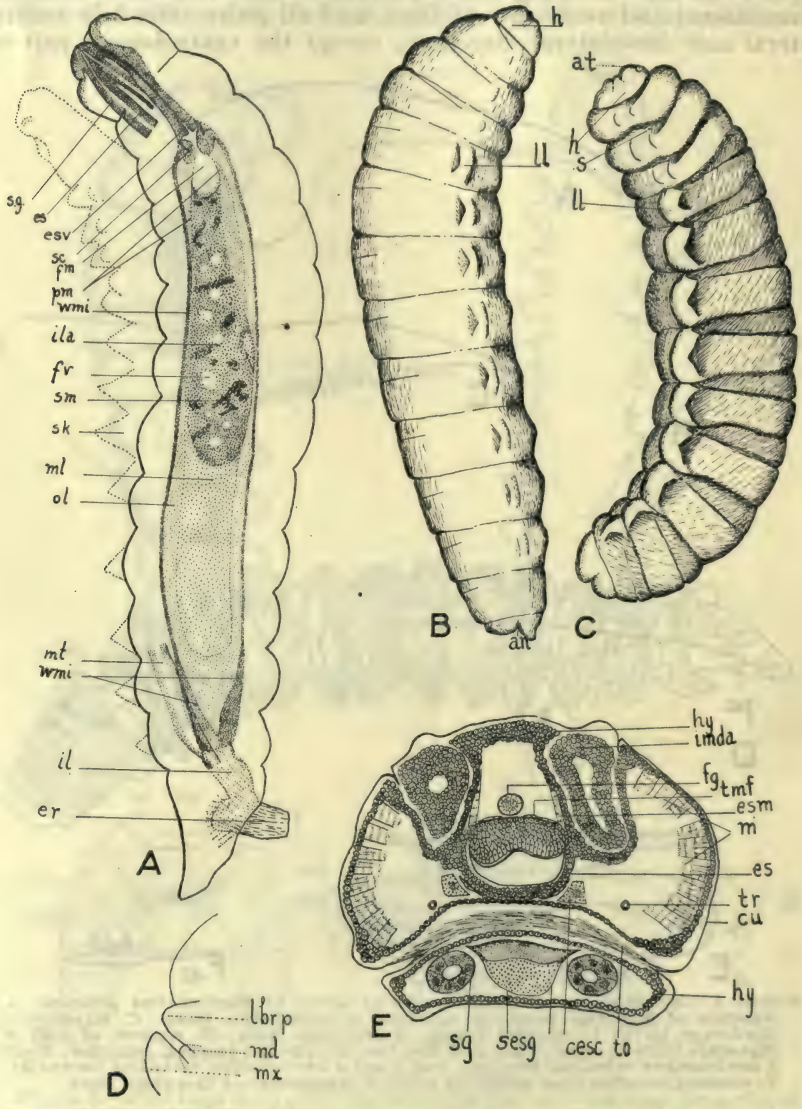

FIGURE 5.—Second, third, and fourth stages and head parts of larvae of *Macrocentrus gifuensis:* A.—Second-stage larva in outline, showing digestive tract. The salivary glands and Malpighian tubes are abbreviated. B.—Third-stage larva, side view. C.—Fourth-stage larva. D.—Cross section through head of second-stage larva. E.—Vertical section through head of larva just in front of brain

mid-intestine before feeding is a slender cylindrical tube; after feeding it is distended and slightly more oval in shape and is filled with a creamy yellowish, granular substance consisting of fat globules in the process of being digested. Near the anterior end the short

peritrophic membrane (*pm*) in early stages of development can be seen inclosing the undigested food. This membrane is probably secreted by the group of special cells (*sc*) situated in the anterior end of the mid-intestine and grows slowly until it fills most of the stomach. In a group of young larvae the peritrophic membrane in all stages of development may be easily observed and dissected out. No undigested food is ever observed outside of it in any larval stage.

In segment XII the mid-intestine joins but does not communicate with the hind-intestine. This organ is in two distinct parts, the ileo-colon to which the Malpighian tubes are attached and the rectum which is evaginated in this stage.[7] A pair of simple Malpighian tubes arise from the anterior portion of the ileo-colon and extend forward ventrally, the right one to Segment IX, the left one to Segment X, though sometimes the left one is the longer. A pair of ramified salivary glands empty into a very short common duct in the head.[8] From this point posteriorly, each gland runs along the ventral floor for a short distance, rises somewhat, and again branches into two principal trunks in Segment IV. Each of these trunks subsequently ramifies in an irregular manner into dorsal branches of varying length.

The tracheal system (fig. 4, D) is composed of two lateral longitudinal trunks connected anteriorly by a dorsal transverse commissure located in the first segment and posteriorly by a ventral commissure in Segment XIII. Ramifying branches extend to the head from both the anterior commissure and the lateral trunks. In each segment three lateral branches arise from each of the main trunks; the first two of these supply principally the inner organs, one extending dorsally and the other ventrally, while the third branch supplies the outer organs, such as muscles, fat, and hypodermis. This branch (fig. 4, E, *c*, *d*) runs in a ventrolateral direction for a short distance and separates into two parts, one part supplying the ventrolateral lobe and the other supplying the dorsolateral lobe. Each of these subbranches is, however, subsequently ramified many times, and these smaller branches wander about from the dorsal lobe to the ventral one and back again. The lobes as well as the body proper have many tracheal terminations in the hypodermal layer, but there are no more tracheae or tracheal terminations in these lobes than there are in the other parts of the body surface, i. e., in the body cavity between these lobes and in the head. Segment XIII has fewer tracheae than the other segments; the evaginated rectum has no tracheae. There are no spiracles.

The nervous system consists of a 2-lobed brain, the subesophageal ganglion, and 12 distinct segmental ganglia; lateral branches arise in each ventral ganglion.

The fat body is not conspicuous, though the small groups of fat cells may be seen between the muscular layer and the digestive tract.

The reproductive organs are represented by two small oval gonads located in the posterior part of the visceral cavity.

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[7] This protrusion of the rectum does not in any way resemble the anal vesicle of certain other braconid larvae such as Apanteles and Microgaster. The writer is of the opinion, with Weissenberg (*32*), that it is not a true anal vesicle.

[8] According to Paillot (*17*), in the species called by him *Limnerium alkae* E. and S. (called by Thompson and Parker (*29*) *Eulimneria crassifemur* Thoms.), parasitic in *P. nubilalis*, there is a pair of silk glands with a single duct and a pair of salivary glands with separate ducts. The writer has carefully studied *L. alkae* and finds that this observation is an error. In no ichneumonid, braconid, or chalcid larva has the writer ever observed more than a single pair of such glands.

Tegumentary muscles can be observed extending from segment to segment, but none are present in the lateral lobes. They are described more fully for the fourth stage.

The circulatory system is of the usual hymenopterous type. (See description of the fourth-stage larva.)

The histoblasts of the adult external appendages, such as wings, legs, and reproductive organs, can be distinguished as thickenings in the hypodermis.

The fully fed larva differs little from the newly hatched larva except that it is larger and slightly swollen, the stomach contents show prominently, and the lateral lobes are less conspicuous.

During the molting process the old head capsule splits, the head is lifted out, and the cast skin slips backwards ventrally, often being partially retained, however, until the larva reaches the third or even fourth stage.

SECOND STAGE

Length of newly-molted larva 2.08 mm., width 0.4 mm. (length after feeding 3.8 mm.), width of head 0.3 mm. (Fig. 5, A.)

The color is the same as in the first stage, but less transparent.

The second-stage larva is composed of a somewhat globular head and 13 body segments; the general form is cylindrical, tapering slightly anteriorly and posteriorly; the last segment is pointed and bears dorsally the evaginated rectum.[9] Slight ventrolateral and dorsolateral bulges are present where the lobes existed in the previous stage. There are no body spines or sensorial papillae or spiracles.

The head is scarcely more heavily chitinized than the body. The mouth parts are distinctly delineated. There are no mandibles; the points where they will later appear are represented by fleshlike lobes. (Fig. 5, D, *md.*) Sensory papillae are present on the various mouth areas.

The internal anatomy is much the same as in the first stage, with the exception of the following points: The mid-intestine has increased in size and fills the greater part of the body cavity. The peritrophic membrane with its contents fills about half of the mid-intestine; the fat body is developing by the increase of the size of its cells, interspersed among which are numbers of urate cells with their granular white contents showing prominently.

THIRD STAGE

Length 3.5 mm., width 0.6 mm., length of chitinized tip of mandible 0.56 mm. (Fig. 5, B.)

The larva of this stage, while somewhat similar to that of the second stage, is proportionally less elongate and resembles more in general conformation the typical hymenopteriform larva. Segment XIII is shorter and the rectum is not or but little evaginated. The mandibles (fig. 4, B) have reappeared and are simple and rather blunt, very lightly chitinized, and have a rounded, slightly projecting irregularity on the posterior edge which might be called a tooth. The irregularity is situated at a point coincident to the most distal of the real teeth which appear on the fourth-stage mandible. There are no spiracles; the body is without spines or sensorial setae.

[9] Fink (5), in his illustration of the second-stage larva, shows the anal opening at the extreme end of the tenth abdominal segment, and only part of the rectum evaginated. In *M. gifuensis* the anal opening is dorsad of the terminal point of the tenth segment and the whole of the rectum—up to the point where it joins the ileo-colon—is evaginated.

FOURTH STAGE

Size, Color, and Form

Length 4.5 mm., width 1 to 2 mm., width of head 0.5 mm., length of mandible 0.0937 mm., width of thoracic spiracle 0.0375 mm., abdominal spiracles 0.0281 mm. (Fig. 5, C.)

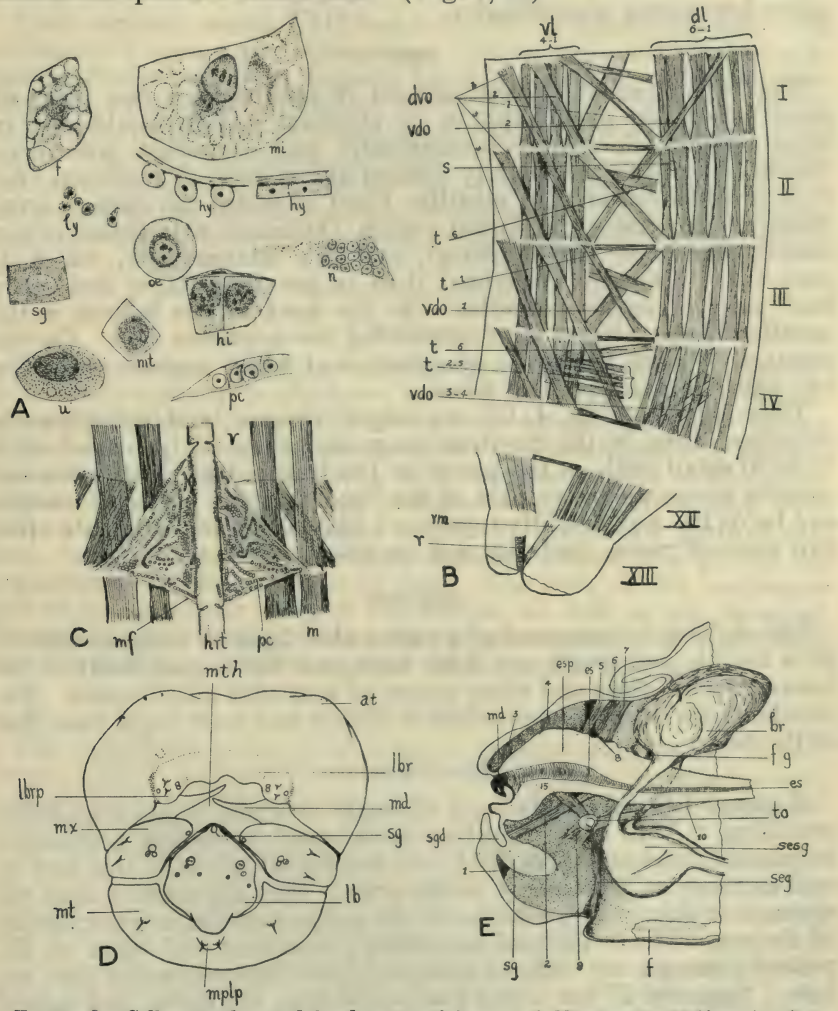


FIGURE 6.—Cells, muscles, and head parts of larvae of *Macrocentrus gifuensis:* A, Cells of various organs of the larva, all drawn to the same scale (Bouin's, glychemalum); B, musculature of larva, Segments I, II, III, IV, XII, and III; C, segment of heart, showing muscular fibers and pericardial cells; D, front view of head of fourth-stage larva; E, side view of head with half (including the salivary glands) cut away

The color is a translucent grayish white, with creamy-yellowish mid-intestine, fat body, and white urate cells prominent.

The larva of this stage is of the typical hymenopterous shape, being composed of a head and 13 body segments. It is arched dorsally and is widest near the middle. The large lateral lobes due to transverse tegumentary muscles (fig. 6, B, *t* 2–5) in each abdominal segment give it a somewhat flattened appearance.

External Anatomy

The principal difference in the general aspect of the larva of this stage as compared with the larva of the third stage is that the lateral lobes are more pronounced, the urate cells are larger, and the "antennae," mandibles, spiracles, and tegumentary spines are visible under low-power magnification.

HEAD

The head is roughly heart shaped in outline with two pairs of short tubercular protuberances, or antennal rudiments, located in large circular elevations dorsolaterally and somewhat anteriorly. The buccal regions are clearly defined and consist of a labrum (fig. 6, D, *lbr*), two prominent maxillae (*mx*) in which the mala is quite distinct from the cardo-stipeal region (although this detail is not clearly shown in the drawing), and the labium (*lb*), which is even more distinctly delineated than in previous stages and bears four pairs of sensory papillae. At the apex of the labium is the opening of the salivary duct containing the spinneret (*sg*). On the mentum, or area below the maxillary and labial regions, there are two pairs of small sensory spines.

The mandibles (fig. 4, C) are larger, sharper, and more heavily chitinized than in the previous stage and they are provided with 17 to 20 small teeth on the posterior (cutting) edge. The tentorium extends across the lower part of the head near the posterior margin and holds the walls rigidly together. The mandibles articulate upon two pairs of ramae (inferior and superior) of the epistoma.

SKELETON

The skeleton is composed of a rather thin layer of compact cuticle. It is flexible and tough and folds back and forth upon itself at the intersegmental lines and other points of muscular attachments. The cuticle of the head and tentorium is thicker and more rigid than that of the body.

CUTICULAR SPINES

Segment I bears a wide band of small cuticular spines completely encircling it, with a small median dorsal patch extending posteriorly to join the band on Segment II; the individual spines in this area as well as those on the margin of the armed band are smaller than the spines near the middle of the band; the spines near the anterior border of the segment are inclined somewhat posteriorly and those on the posterior margin are inclined anteriorly; the intersegmental lines are bare. Segment II has a like band encircling the dorsal and lateral surfaces, while immediately around the spiracles is a small unarmed area. Segment III has a similar band but it is narrower and does not extend so far ventrally as in Segment II; though there are no spiracles in this segment, the "spiracular" area is without spines as in Segment II. Segment IV is similar, but the armed band does not extend so far ventrally and the dorsal spined area connecting the band of Segment IV with that of Segment V is smaller and has fewer spines. In Segment V the armed band is diminished in width dorsally and is only a narrow strip extending along the anterior margin of the segment, and the dorsolateral areas only are covered by the

spines. In Segment VI only the dorsolateral areas are armed, Segments VII to XI are similar, while in Segment XII these areas are reunited dorsally to form the band covering the dorsal and lateral areas. Segment XIII is bare.

SENSORIAL SETAE

Each segment except XIII has a number of small sensorial setae interspersed among the tegumentary spines, these setae varying in number from about 40 on Segment I to 32 on the abdominal segments. They are not constant in number or location on any two segments of a single individual nor on analogous segments of two different specimens. The only constant arrangement observed is that on Segment I there is a more or less irregular row of these setae ventrally on the left side near the anterior margin of the spined band, while on the right side the corresponding group is near the middle of the armed band.

INTERNAL ANATOMY

HYPODERMIS

The hypodermis is a thin secreting layer just underneath the cuticle. It is uniform in thickness save in the head, where it is considerably thickened, especially around the mouth parts and the top of the head and at several points where the histoblasts will appear. The cells of the hypodermis (fig. 6, A, *hy*) are regular in size, more or less hexagonal in shape, but globular when sparsely placed, with distinct and easily stained round nuclei. In the thicker parts of this layer the cells have their nuclei in different planes, thus giving the appearance of several strata of cells. The cells of the esophagus and of the posterior part of the rectum, as well as the imaginal Malpighian tube buds and those of the extreme anterior end of the salivary glands, are similar to the hypodermal cells.

HISTOBLASTS

The histoblasts, or imaginal disks as they are often called (in reference to adult appendages), are those cells of the hypodermis which become differentiated by their activities more or less early in the larval life to produce certain organs of the adult.

At first these histoblasts are represented by a slight thickening of the hypodermal layer, but when the larva has reached full growth the cells have multiplied and pulled away from the cuticle, leaving it bare at that point, and the organs begin to form. The most conspicuous ones are the antennal histoblasts, which are situated in the head, one on each side and slightly behind the labrum (fig. 5, E, *imda*); the leg disks, which are located ventrally in Segments I, II, and III; the wing pads, which are located laterally on Segments II and III; and the histoblasts of the external reproductive appendages (fig. 7, D, *idr*), located ventrally in Segments XI and XII in the female larva, and in Segment XII in the male larva. The imaginal cells of the mid-intestine are located between the epithelial cells near the basal membrane. (Fig. 7, C, *ic.*) The imaginal cells of the anterior intestine are located at the distal extremity of the esophagus, generally known as the esophageal valve (*esv*). The

hypodermal imaginal cells are noticed in abundance in late fourth-stage larvae around the spiracles in each segment, from which point they spread, sweeping off the old hypodermis as transformation takes place. The imaginal Malpighian tube buds are located on the posterior extremity of the ileo-colon.

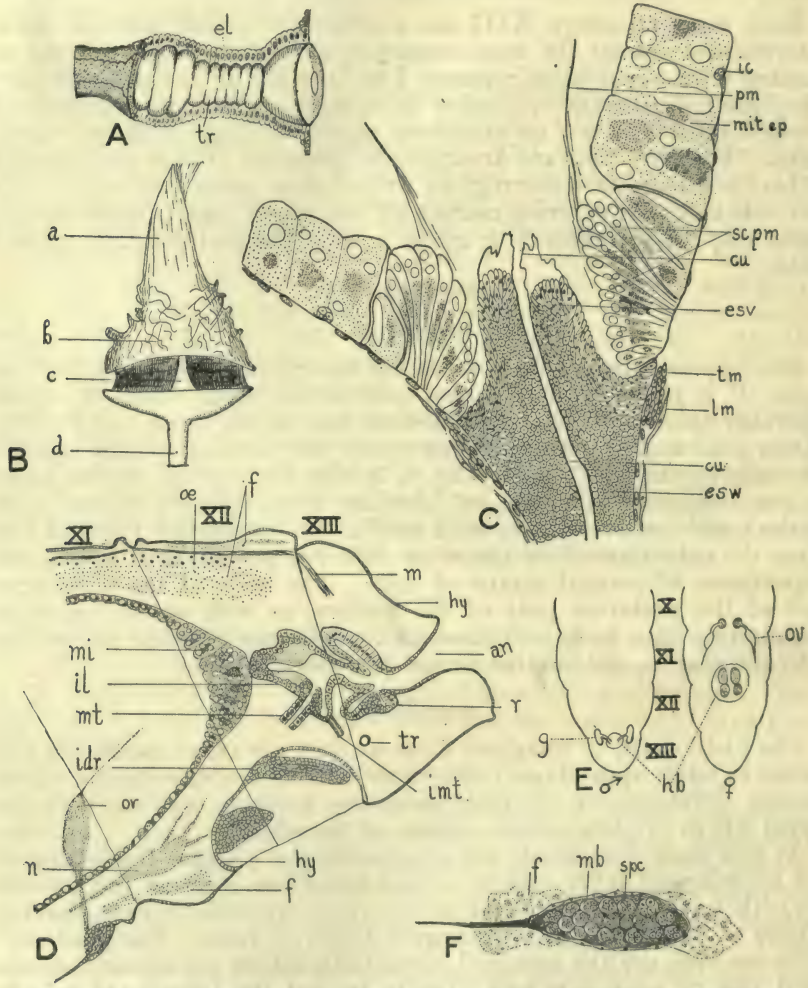


FIGURE 7.—Larval parts and reproductive organs of *Macrocentrus gifuensis:* A, Spiracle of a fourth-stage larva with part of epithelium removed; B, impression in hardened silk of the interior of the salivary gland opening; *a* is the exterior thread, *b* is a portion accumulated during the hardening process, *c* is the dividing line at the point where the two threads come together, and the shaded areas on each side are the imprints of the presses; C, median longitudinal section through anterior end of mid-intestine of fourth-stage larva to show esophageal valve; D, longitudinal section through posterior end of body of larva slightly to left of median line; E, grosso modo view of male and female reproductive organs in the larva; F, section through gonad of male larva

RESPIRATORY SYSTEM

The tracheal system is essentially similar to that described and figured in the first stage. (Fig. 4, D.) It differs from the first stage in that there are present nine pairs of open spiracles (fig. 7, A) situated laterally and slightly dorsally on the anterior margins of

segments II and IV to XI inclusive, connected with the lateral tracheal trunks by a spiracular branch. The lateral trunks are greater in diameter in proportion to the terminal tracheae than are those of the first stage. In each segment the lateral trunks give off branches which ramify to the fat, hypodermis, and other internal organs. The head is supplied from branches arising in the first thoracic segment, while in the last abdominal segment branches are sent out from both trunks and the short transverse ventral commissure to supply the rectum, muscles, and the other organs and cells of the segment.

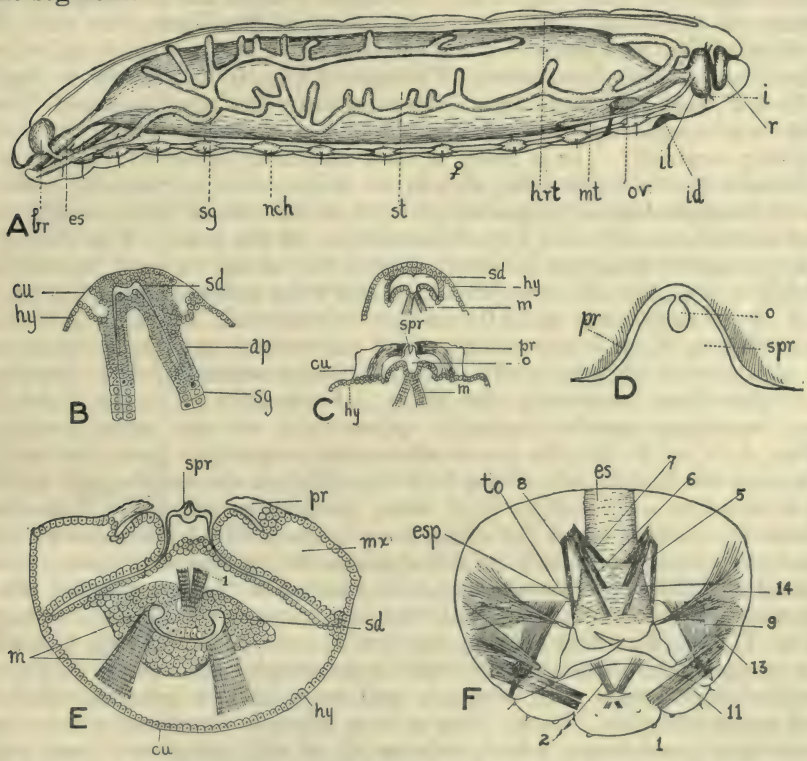


FIGURE 8.—Internal organs and head parts of larvae of *Macrocentrus gifuensis:* A, side view of fourth-stage larva, showing internal organs; B, section through salivary duct; C, sections through salivary duct and spinneret; D, spinneret seen from above; E, horizontal section through front part of head at level of spinneret; F, musculature of head of fourth-stage larva, seen from above

NERVOUS SYSTEM

The nervous system (fig. 8, A) is of the usual hymenopterous type[10] consisting of brain, subesophageal ganglion, and ventral chain. The ventral chain extends to segment XI; the two cords connecting the ventral ganglia are not fused as in certain Chalcididae but are quite distinctly separated. The ventral chain is composed of the subesophageal ganglion and 11 other distinct ganglia, the

[10] Voukassovitch (*31*) has written a very good account of the biology and larval anatomy of *M. abdominalis,* a parasite of *Psammotis hyalinalis.* In his drawings of the fully developed larva Voukassovitch figures two voluminous growths appearing on the posterior end of the nerve chain. These organs are in reality the histoblasts of the reproductive appendages which are supplied with nerve branches from the terminal ganglion.

last one of which probably represents two ganglia that fused since the first stage, as there are two pairs of nerve branches given off from it.

The so-called sympathetic nervous system is represented by a small spherical frontal ganglion (fig. 5, E, *fg*) situated above the esophagus just in front of the brain.

The writer has not observed the corpora allata.

DIGESTIVE SYSTEM

The digestive tract (fig. 8, A) is composed of the mouth, esophageal pump, or pharynx, esophagus, mid-intestine, hind-intestine (which is divided into two distinct portions, ileo-colon and rectum), salivary glands and Malpighian tubes. The mouth (fig. 6. E), pharynx (figs. 6, E, 8, F, *esp*) and esophagus (*es*) constitute the fore-intestine. The first is a simple opening at the anterior end of the head situated slightly ventrally. It is lined with a cuticular layer which is continuous with the outer skin; this layer of cuticle is surrounded internally (morphologically speaking) by a thick tube of cells similar to and continuous with the hypodermal layer of the head. The esophageal pump or pharynx is instrumental in taking in food material, which it does by the contraction of the four pairs of muscles (fig. 8, F, 5–8) extending dorsally to the cranial wall above it and one pair (fig. 6, E, 15) extending to the tentorium, and the relaxation of the mouth muscles and subsequent contraction of the circular muscular fibers encircling the pump. From this point the esophagus, becoming smaller, extends posteriorly to the mid-intestine. (Fig. 8, A, *st.*) At the point where the esophagus joins the mid-intestine the histoblasts of the fore-intestine, or the esophageal valve as it is often called (fig. 7, C, *esv*), project considerably into the stomach. At this point the outer muscle fibers (*tm*) are more abundant, the cuticle extends into the stomach beyond the valve, and the cells of the valve are somewhat elongated in various places. The junction of the esophagus with the mid-intestine is quite distinct. (Fig. 7, C.) The first cells in the wall of the mid-intestine (*scpm*) are grouped immediately posterior to the esophageal valve; they are large elongate cells with elongate and more or less irregular nuclei and many globules. From these cells as already described comes the peritrophic membrane which incloses all of the undigested food and fills three-fourths or more of the mid-intestine; caudad of this group of cells is the mid-intestinal wall proper (*mitep*). This wall is composed of an outer layer of muscle fibers, a basal membrane, and a layer of large epithelial cells with elongate irregular shaped nuclei, containing granular and fibrous matter and many globules of unknown nature, most probably food material being absorbed. Between the cells of the wall on the outer edge can be seen here and there bunches of small imaginal cells (*ic*). In the posterior end of the mid-intestine the cells of the wall are greater in length near the point where it joins the hind-intestine. The lumen of the mid-intestine is not continuous with that of the hind-intestine. In late fourth-stage larvae, however, these layers become less distinct at that point; the walls of the two intestines fuse but leave the lumen blocked by fibrous and granular matter until defecation takes place.

The hind-intestine is distinctly divided into two portions, the ileo-colon or anterior portion and the rectum or hinder part. The ileo-colon, which anteriorly is a short narrow tube, thickens abruptly into a more or less conical enlargement into which the two Malpighian tubes are inserted. (Fig. 8, A, *il.*) The extreme posterior part of this enlargement bears the imaginal buds of the adult Malpighian tubes (figs. 7, D, 8, A, *imt*) (before the larva has spun these tubes actually grow to a length of a millimeter or more). Immediately caudad of this point is a marked constriction, which separates the ileo-colon from the rectum (*r*). This organ has thick walls composed of cells with small round nuclei (fig. 6, A, *hi*) (not unlike the other cells of the hind-intestine) and a wide slitlike lumen continuous with that of the ileo-colon. From this enlargement posteriorly to the anus the rectum is a straight though short ribbonlike tube flattened dorsoventrally. The whole of the hind-intestine is covered exteriorly by layers of muscle fibers.

The salivary glands (fig. 8, A, *sg*) consist of four dorsally branched longitudinal tubes, two on each side of the mid-intestine, extending from the posterior extremity of this organ to the thorax. The tubes on one side come together in the thorax, from which point a single tube continues forward ventrally to the head, where it is joined just below the mouth by the one from the other side. The common duct is a short tube, U-shaped in cross section, extending upward to the external opening at the apex of the labium. (Fig. 8, B, *sd*, C, *o.*) The spinneret (fig. 8, E, *spr*) lies in the opening of the salivary gland on the inferior lip. It is an elongate-oval passage formed by two chitinous prongs which are outgrowths of the lower labial lip. The superior lip of the opening is shaped like an inverted V, and the cuticle on each side of the V is considerably thickened, thus forming two "presses" (fig. 8, C, D, E, *pr*) which, when pulled into position against the spinneret, oblige the silk to pass out through this organ. The posterior wall of the salivary duct is impressed by a vertical median groove. The cells surrounding the duct which secrete the chitinous lining are similar to and continuous with the hypodermal cells. Immediately posterior to the point where the two ducts separate, however, the cells become differentiated into large secretory cells (fig. 8, B, *sg*) with oblong nuclei of considerable size (fig. 5, E, *sg*), and this type of cell continues to the distal extremity of the glands.

The Malpighian tubes (figs. 7, D, 8, A, *mt*) are simple tubes composed of large cells with round or oval nuclei and a central lumen which opens into the hind-intestine. Their position is the same as in the first stage.

TEGUMENTARY MUSCLES

The tegumentary muscles include those of the head and those of the body. Those of the head are the two pairs of mouth muscles (fig. 6, E, 3, 4) extending from the dorsal wall of the mouth to the cranium above it; the eight dorsal pharyngeal muscles, three pairs extending from the pharynx dorsad of the cranium (figs. 6, E, 8, F, 5, 6, 7) and one pair attached laterally but extending dorsad and slightly anteriorly to the cranium (figs. 6, E, 8, F, 8); and a ventral pair (fig. 6, E, 15) extending ventrally and slightly posteriorly from

the lower pharyngeal wall to the tentorium. Those of the salivary duct are, one pair of short muscles situated anteriorly to the duct under the spinneret (figs. 6, E, 8, F, 1), and one pair attached to the posterior wall of the duct (figs. 6, E, 8, F, 2) and extending posteriorly and somewhat laterally to the lower wall of the pharynx. One pair of rather frail muscles extends from the tentorium posteriorly to the esophagus. (Fig. 6, E, 10.) The maxillary muscles are attached posteriorly to the tentorium and extend obliquely forward laterally and somewhat ventrally to the maxillary suture. (Fig. 8, F, 9.) The labial muscles attach laterally and somewhat ventrally near the posterior border of the head and extend anteriorly and inward, attaching to the labial suture. (Fig. 8, F, 11.) The mandibular muscles, the most prominent and voluminous of the head muscles, attach laterally to the head wall, almost filling the cheeks, and converge inwardly, attaching to the cartilages on the mandibles. One group, the extensors (fig. 8, F, 13), is not so voluminous as the other group, the flexors (fig. 8, F, 14).

The body muscles are as follows (fig. 6, B) (described from a preparation of the right half of the body): Segment I is provided with a dorsolateral group of six (*dl* 6–1) and a ventrolateral group of four longitudinal (*vl* 4–1) muscles; three isolated muscles extending obliquely in a dorsoventral direction (*dvo* 1–3); two isolated muscles extending obliquely in a ventrodorsal direction (*vdo* 1–2); the above muscles extend from the posterior to the anterior border of the segment; in addition there is a short transverse muscle extending along the intersegmental line (*t* 1), and another in the anterior quarter of the segment (*t* 6).[11] Segment II is similar except that the ventrodorsal 2 is absent; Segment III is similar to II; Segment IV (first abdominal) is similar to II with the addition of four other short transverse muscles (*t* 2–5) and two ventrodorsal oblique (*vdo* 3–4); Segments V to XI are similar to Segment IV, while XII has only the dorsolateral and ventrolateral groups, one of which extends from the anterior border of the segment to the rectum.

CIRCULATORY SYSTEM

The heart is a muscular tubelike organ with a number of segmental intake valves not unlike the typical hymenopterous heart as described by Nelson (*16*) for the honeybee. It originates in the twelfth abdominal segment and extends anteriorly. The aorta, a small straight tube, conducts the blood forward to the brain; the heart and aorta constitute the dorsal vessel and this organ is suspended from the body wall by tiny fibers. The heart proper is surrounded by pericardial cells. (Fig. 6, C, *pc.*) It is operated by groups of small muscular fibers extending laterally to the intersegmental lines where they are attached, and muscular fibers within its own walls; the pericardial cells lie between two layers of these muscles, thus forming what is called the dorsal diaphragm.

REPRODUCTIVE ORGANS

The reproductive organs of the male larva (fig. 7, E, F) consist of two small oval gonads located in the posterior part of the visceral

[11] These muscles are numbered to conform with a scheme already elaborated for other species in earlier publications (*19*).

cavity and attached by a short stalk to the center of the simple histoblast located on the floor of the abdomen at the posterior edge of the ninth abdominal segment. Those of the female larva (fig. 7, D, E) consist of two small ovaries in the seventh abdominal segment attached by short stalks to the small imaginal disks located on the floor of this segment. In addition there are the histoblasts of the ovipositor and sheath located on the floor at the posterior edge of the eighth and anterior edge of the ninth abdominal segments.

FAT BODY AND URATE CELLS

The fat body (fig. 6, A, *f*) consists of four principal lobes extending longitudinally between the stomach and the layer of tegumentary muscles as well as small pieces between the hypodermis and muscular layer.

The urate cells (fig. 6, A, *u*) are interspersed among the fat cells in those portions of the four principal lobes which are in contact with the midintestine. There are no urate cells in the thorax. The oenocytes (fig. 6, A, 7, D, *oe*) are found singly or in groups, principally laterally near the spiracles.

FIGURE 9.—Three cocoon colonies of *Macrocentrus gifuensis*. The shriveled skin of the host may be seen attached to the lower half of each of the two vertical masses. × 2½

THE PREPUPA AND PUPA

The prepupa and pupa are of the usual hymenopterous type. The female pupa can easily be distinguished by the long ovipositor which is curved dorsally and extends almost to the head.

THE COCOON

The silk spun by the larva is at first of a delicate, fluffy, cottony texture and retains this appearance until the cocoons are almost completed, when each cocoon takes on a glistening finish due to its glossy, compact inner texture. Each cocoon bears internally at the anterior end a small thick disk of hardened material forming a round cap at this point. The whole mass is of a light-brown color through which the larva, and later its dark-brown meconium, can be seen.

The individual parasite larvae which have developed within a single host, upon emergence from it, construct their cocoons gregariously in an elongate mass, with their longitudinal axes nearly parallel. The whole colony forms a cigar-shaped mass about 23 mm. long by 4 to 5 mm. in diameter, to which is attached the shriveled skin of the host. (Fig. 9.)

BIOLOGY

EMERGENCE

When ready to emerge, the adult by its contortions splits the pupal skin inclosing it, works it off the body in pieces, chews off the small disklike cap on the anterior end of the cocoon, and shoves its way through the remaining threads of silk inclosing the cocoon mass.

Emergence may take place at any time of day or night. Usually the individuals of a single colony issue more or less simultaneously, although in some cases emergence may extend over a period of about 24 hours.

LIGHT REACTIONS

The adults are positively phototropic but not intensely so. The degree of this positive phototropism is such that it is a help in manipulating the adults in laboratory breeding and rearing work.

FEEDING

The adults of both sexes readily absorb plain water or water sweetened with sugar or honey. The best food is dilute fresh honey water which they eat in such quantity that their abdomens become distended. They partake of concentrated sugars but slightly, however. Pure water prolongs their lives somewhat.

OOGENESIS

At emergence there is at least one fully developed egg in the lower part of each ovarian tube; sometimes there are two, and occasionally three, thus allowing for a total of 24 eggs or more at the time of emergence. Immediately above the developed egg or eggs in the maturation chambers there are from one to three oocytes in different stages of development, the most advanced being, naturally, the one nearest the lower extremity of the tube; the nurse cells are observed to be pouring their contents into the oocytes. Each oocyte has a large conspicuous nucleus surrounded by granular matter, which is in turn inclosed in a membrane of cellular structure with prominent, easily stained nuclei. The terminal chamber is filled with nurse cells and germ cells in the process of division and differentiation.

Females kept at a temperature of 25° C. without moisture and fed on sugar water for three days were observed to have two or three developed eggs in each ovarian tube, thus augmenting the original number present at emergence by at least 24 eggs in three days. In two cases one egg was found down in the paired oviducts after two days, and in one case three eggs, but in other examinations after a longer period no eggs were found down in these ducts. Females 15 days old have from 5 to 8 developed eggs in each ovarian tube, thus allowing for a total of about 200 eggs. Counts of eggs and oocytes show that a female is capable of developing at least 200 to 300 eggs.

COPULATION

The males are sexually active immediately after emergence and when they are placed with females mating takes place immediately.

The female struggles to prevent copulation but the male usually overcomes this resistance. No time is lost on preliminary maneuvers; the male mounts upon the female, bends the tip of the abdomen under that of the female and fertilizes her, the contact lasting but a few seconds. During this time the female may remain more or less still or she may walk around the cage dragging the male with her. In this case the male retains his hold only by the abdominal claspers while struggling to brace his feet on the surface of the cage. The female does not usually permit a second mating; her struggles to prevent it are violent and consistent, though sometimes the male overcomes this resistance and a second mating takes place. Sexual activity of the males is more pronounced when they are not confined in a small space. If males and females emerge together in a small vial a limited activity is manifested by the males, but when this lot is released into a larger container the males again start mating. This is true also of a great number of other parasitic insects. It is probable that in a small space the air becomes thoroughly saturated with the odor of the females and the males who become satiated with this scent are less responsive to it as a mating stimulus. This factor and the crowding which takes place in a small space render mating difficult in case there are a number of individuals present.

OVIPOSITION

THE FEMALE DURING OVIPOSITION

Females are not ready to oviposit immediately after emergence but require a period of three or four days to develop their interest in the host, an interest increasing as the number of eggs in the ovaries augments; by the fourth day interest is lively, and by the eighth day it is intense.

Oviposition takes place best at a temperature of about 22° to 25° C. The females show little or no interest in host larvae when the temperature drops below 20°.

Activities are decidedly more brisk in the morning before the daily feeding. After feeding the females are somewhat sluggish and their interest wanes. Bright sunlight seems to stimulate oviposition activities.

Females could not be induced to oviposit in Pyrausta eggs.

When supplied with host larvae in cells or webs on leaves of Rumex, Artemisia, corn, etc., the female immediately directs her attention to the infested point. The first indication of the oviposition stimulus is the slight unsheathing of the ovipositor. It is probable that this movement brings an egg down from the oviduct to a position of readiness in the vagina or proximal end of the ovipositor. This supposition is strengthened by the observation that the females have a tendency, once the ovipositor is unsheathed in this manner, not to sheath it again until an egg has been laid. A few seconds after this movement the female raises the end of the abdomen, brings the tip of the ovipositor forward to a point under the body, and commences to prod rapidly the area where the larva has been feeding. The antennae are extended forward and somewhat separated, the wings are raised, the ovipositor is held pointing forward and downward, the sheath describes a loop upwards and

backwards, curving around the end of the abdomen until it points forward and downward. (Fig. 10.) The sheath retains the ovipositor in its tip at a point about one-third to one-half of the distance from the base and seems to direct that organ in the forward and sidewise exploration thrusts. Whether or not the sheath actually plays any considerable part in the guiding of the ovipositor is somewhat doubtful, as it probably is pulled into this position by the ovipositor and retains a hold on the latter as the point of this instrument is brought forward between the front legs by the group of strong muscles attached to its base. This is the only position the sheath can assume unless it releases the ovipositor entirely, in which case it straightens out and points upwards posteriorly; this actually happens quite often, but the work of exploring and stinging the host larvae continues just as well without the aid of the sheath. It is noted, however, that the ovipositor can be bent slightly in any direction at its middle or near its tip by the action of the muscles of the sheath.

FIGURE 10.—Female *Macrocentrus gifuensis* in position for ovipositing. × 6

When the female perceives that a larva is actually present she becomes excited and her thrusts become more frequent; if the point of the ovipositor comes into contact with the larva it is thrust into the latter, an egg is quickly laid, and the ovipositor is almost immediately withdrawn, straightened out, and sheathed.

Because of the manner in which she manipulates her long ovipositor it is practically impossible for a female to sting a free-crawling larva. The larva must be in a web or a hole whence its escape will be retarded for the brief period of time necessary to allow the female to locate and sting it.

The places most explored and apparently the most agreeable for the female to give her thrusts are under the edges of a leaf where the leaf is held flat against another surface and in holes in the stems and leaves, etc. If larvae are free on the surface of a leaf and the spot is designated by frass or a bit of web, the female will go through her typical exploration movements for hours and often not hit a single larva, especialy if the larvae are small (first or second stage). The thrusts are made in any or all directions and an egg is laid only if by chance the ovipositor encounters the larva. During this time the point of the ovipositor may be in contact with the leaf in the vicinity of the larva, but it does not penetrate the leaf. Isolated larvae attract the female little or not at all. Occasionally the female, thrusting vigorously to lodge the sting, will apparently "pursue" or "wrestle" with a larva driven from its

feeding point, but when such cases are closely examined it is often found that the larva is retreating and is dragging the female by a leg which it has seized in its mandibles.

After giving a thrust the female withdraws her ovipositor, sheathes it, and pauses for an instant as if to repose after the labor of oviposition. She does not, however, abandon the spot, but almost immediately resumes her exploratory thrusts, and if the larva is again encountered it receives another thrust. The larval burrow with its accumulation of frass and web has a very strong attraction for the female. Even though the larva leaves the burrow, the female will remain in its vicinity for a considerable time (an hour or more), thrusting vigorously around and into the empty burrow.

No expression can better describe the actions and movements of the females than to say that they appear to be extremely stupid. They can not locate the host precisely and often stumble around over a larva without stinging it at all.

Such behavior among insects is common, however, the rule rather than the exception, and numerous similar cases can be cited. Lundie (*14*) has observed that in the case of *Aphelinus mali* Hald., when this parasite turns and thrusts backwards (as is its custom) to oviposit in *Eriosoma lanigerum* Hausm., if the aphid moves away the parasite remains there for some moments thrusting into the air. The writer has observed an identical proceeding in the case of (*Chalcis*) *Brachymeria fonscolombei* Duf. when depositing in larvae of species of Sarcophaga. Another case analogous to these has been observed by the writer in mating adults of *Eulimneria crassifemur* Thoms. (another parasite of *P. nubilalis*). The male moves around the immobile female, fanning her with his wings during a preliminary courtship period; if the female moves away the male will nevertheless continue his fantastic gyrations for some time before he eventually discovers that his mate has walked away.

THE HOST LARVA DURING OVIPOSITION

The attacked larva generally shows its excitement by quick contortions of the body and by retreating farther into its burrow. If the burrow is shallow and the larva can not retreat, it leaves the burrow at once and squirms away rapidly; if the burrow is of moderate depth but not so deep as to permit complete escape from the sting of the female, thus presenting ideal conditions for oviposition, the larva will most certainly receive a number of additional thrusts; if the burrow is very deep the larva by retreating escapes completely from further attack for the moment at least.

When touched by a Macrocentrus, the larva makes vigorous efforts to escape. These efforts are tripled after it has received a trust, and often it will rush out of its shallow burrow even when a female is standing at the opening thrusting vigorously into the interior. This sudden rush usually dismays or upsets the female, and in a case of this sort the additional thrust given at this moment does not succeed.

POSITION AND NUMBER OF EGGS IN HOST

The eggs are lodged in almost any place in the body. The writer has observed them free in the general body cavity, in the epithelial

tissue of the mid-intestine, in fat, muscles, oenocytes, or stuck close to the hypodermal cells; sometimes (but rarely) they are laid between the hypodermal cells and the cuticle. It is possible that some are placed in the digestive tract, but these would probably be evacuated.

One of the phases of the biology of *M. gifuensis* which the writer has tried to clarify is the number of eggs laid in a host by a female at a single thrust of the ovipositor. The importance of this point can be appreciated when it is considered in connection with the polyembryonic development of this species. Unfortunately in actual practice it is not easy to demonstrate this point as it would be with a monembryonic species. The simple process of allowing a female to pierce a larva and then recovering the egg can not be relied upon for the reason that in most cases no egg can be found. While it is possible that the female gives some futile thrusts, it is more probable that the majority of her thrusts are successful and that the failure to find an egg to account for each thrust may be explained by the probability of the egg being lodged by chance in some organ of the host and not floating freely out into the dissecting solution.

It is more often the case that parasitic Hymenoptera lay one egg at a single thrust of the ovipositor. There are, however, some exceptions, such as *Apanteles thompsoni* Lyle, which deposits 10 to 20 eggs at a single thrust (*8*), and *Platygaster hiemalis* Forbes, which deposits 4 to 8 (*12*).

The writer concludes, after a long series of observations, that generally one egg is laid at a single thrust. It is possible, however, that in some cases two or three are laid but not more than this number.

The following are some of the principal observations upon which the writer bases this conclusion: (1) Many larvae have been dissected in physiological solutions immediately after being pierced by a female. In most cases no eggs were found therein, in some cases 1 egg was found, and in no case was more than 1 egg found after a single thrust. (2) Larvae having received from 5 to 20 thrusts each were dissected in a physiological solution; 1 or 2 eggs were found in each of several different larvae, with a maximum of 3 in one larva which had received about 15 thrusts. (3) It may be said as an objection to this line of reasoning that should *M. gifuensis* deposit 10 to 20 eggs at a single thrust they might be lodged in a group within a muscle or other host organ. The following data seem to refute this, however: In one case the writer, by attaching the larva as described under the heading technic, caused it to be pierced more than 20 times by a female Macrocentrus. This larva was then fixed and sectioned. A number of eggs were found in it, some free in the body cavity, others in the fat body within muscles, and 1 between the hypodermis and the integument, but they were generally single eggs. No large groups or batches of eggs were found together; occasionally there were 2 or 3 near each other without their presenting, however, the appearance of having been laid together as would necessarily be the case if a large number had been deposited at a single thrust. (4) The long-sustained interest and continued series of oviposition thrusts observed on the part of a single gravid female is another argument in favor of the single-egg theory. As has been stated, a female will continue to sting a caterpillar, provided it can not escape, during an hour or more.

Considering that a female possesses a relatively small number of eggs in her oviduct and that they ripen rather slowly, it seems more reasonable to suppose that she would soon deposit all the available eggs in a few thrusts and then desist.

SEGMENTATION OF THE EGG

The earliest stage of segmentation observed by the writer was in an unstained egg of unknown age (but less than 5 hours). The following is a description of this egg: Length 0.12 mm., width 0.048 mm. There are two cells with clearly defined walls and nuclei in the central part of the egg, surrounded by the granular contents of the egg, and another cell or nucleus of a granular nature but different from the other two at the lower end; this latter may be the germ-cell determinant.

Another egg in about the same stage of segmentation is illustrated from fixed and stained material in Figure 2, B. Figure 11, A, represents an egg less than 5 hours old in which there are four large cells of equal importance and three cells or masses of protoplasmic material of an entirely different nature. It is probable that these three are the polar bodies which will later form the paranucleus, while the four larger ones are blastomeres.

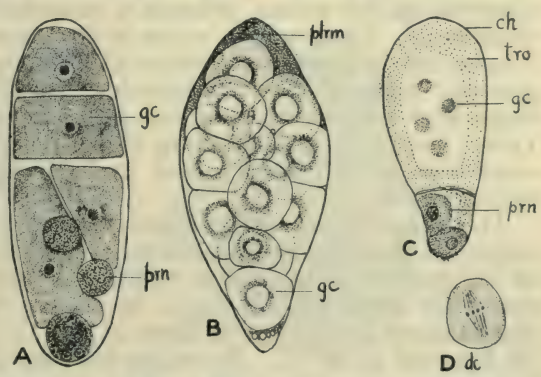


FIGURE 11.—Eggs of *Macrocentrus gifuensis* in different stages of development: A, Egg less than 5 hours old (Bouin's); B, egg less than 5 hours old, showing complete segmentation; C, egg 9½ hours old, showing differentiation into germinative (or embryonic) cells, paranucleus, and trophamnios; D, cell in the dividing stage (metaphase)

Another unstained egg observed in physiological solution is illustrated in Figure 11, B, and the following description applies to it: Length 0.125 mm., width 0.056 mm., age less than 5 hours; there are 14 cells, 2 smaller ones, 10 microns in diameter, and 12 larger ones, 20 microns in diameter; the nuclei are round and clear and each is surrounded by a thin layer of granular matter, none of which occurs inside the nucleus; there are 10 to 12 small round globules of unknown material scattered here and there in the egg but lying outside of the cells; 4 of these are in one end; at the opposite end there is a mass of dense granular material partly surrounding and inclosing the cells of that end; in this material small globules can be seen, and at one point there is a conglomeration of these globules and a thickening of the granular material, resembling a nucleus; this granular substance may be the polar-body material destined to furnish the paranucleus; it extends nearly half way down the egg on one side and about a third on the other side.

Another egg 3 hours old has 18 cells of two sizes (the smaller one being about half as big as the others), but of the same sort, while still another egg 3 hours old has about 32 cells about equal in diameter

to the smaller ones in the 18-celled egg. This egg has conglomerations of granular matter at each pole, and along one side, partially extending in between the blastomeres, but no definite cells or nuclei can be seen in this granular matter.

Other eggs of various ages up to 9½ hours have been observed, but in many of these eggs segmentation is less advanced than in those in Figure 11, B. Often only 2 to 6 cells are present. Figure 11, C, is drawn from an egg 9½ hours old stained in methylene blue. There are 2 cells (polar bodies) in the lower end of the egg and 4 germinative cells in the central part, the former being distinctly separated from the latter by a membrane or line of differentiation; the central cells are in an area of clear material while the remainder of the ooplasm is pushed outward to the periphery where it forms a rather thick wall.

GROWTH AND DEVELOPMENT OF THE EGG

The next stage in the development of the egg (fig. 12, A, B, C), as observed by the writer, presents a remarkable change from the previous stage. The pregerm varies in diameter from 0.016 to 0.027 mm., is spherical in form, has a rather thick outer wall, a layer of smooth granular material, the trophamnios (*tro*), in which is embedded a large oval nucleus of irregular granular content, the paranucleus (*prn*), probably derived from the polar bodies, and two or three smaller cells with small round nuclei, which constitute the germinative center.

This stage is called for convenience the pregerm. It is usually lodged in the adipose tissue where it determines a distinct swelling of the nucleus of the cell in which it is lodged and of the cells immediately around it. B and C in Figure 12 are drawn from a sectioned larva fixed after 43 days at 18° C., while A is from an egg 36 days old at 18° C. No stages between the egg of 9½ hours and the pregerm have been observed by the writer.

The pregerms loose in the visceral cavity have a thinner chorion.

Coincident with the appearance of these pregerms in laboratory-reared larvae, others appear which are similar in structure except that they have no germinative cells (fig. 13, A, B), all their contents being in a central spherical body resembling the paranuclei of other pregerms. These bodies are most probably pseudogerms.

The question naturally arises, "What are the intermediate stages through which the egg passes to form the pregerm?" While no definite answer can be given to this question for the present, the writer proposes two hypotheses.

The first hypothesis is that the egg continues the process of segmentation until a large number of cells of two sorts are present; i. e., a group derived from the polar bodies and a group derived from the blastomeres. The egg then dissociates and these cells scatter in groups of from one to four. When two or more cells cling together, or come together after separation, thus forming a group, a pregerm is formed, provided there is present at least one cell of each sort; a polar cell (or cells) without a blastomere gives rise to a pseudogerm. This hypothesis would explain (1) the small size of the pregerm as compared to the original egg, (2) the small number

of cells present in the pregerm, and (3) the presence of the pseudogerms.

The second hypothesis, which seems more probable, is that each pregerm represents an entire egg which has progressed to a certain

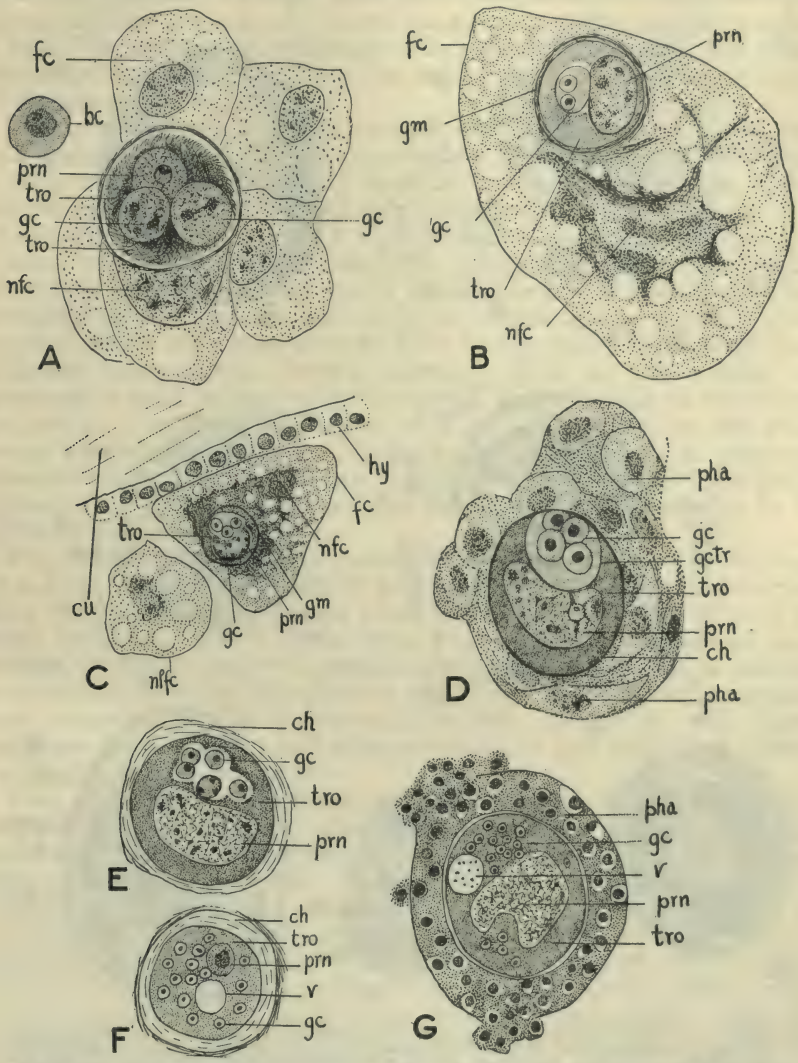


FIGURE 12.—Pregerms of *Macrocentrus gifuensis*. A.—Early pregerm lodged in a fat cell. The two embryonic cells are in anaphase. B.—Early pregerm with two embryonic cells. C.—Early pregerm with three embryonic cells. D.—Pregerm with four embryonic cells. E.—Pregerm with five embryonic cells. F.—Pregerm in which the embryonic cells are not associated in a germinative center (probably an aborted condition). G.—Another pregerm in the same condition surrounded by phagocytes

point in segmentation and that each pseudogerm represents an egg which for some unknown reason (not lack of fertilization) has not segmented in the normal manner, and consequently is without embryonic cells.

The difference in the number of cells often observed in eggs only a few hours old and the number of cells observed in the pregerm could be explained by supposing that some eggs segment more rapidly than others and furnish pregerms such as those shown in Fig-

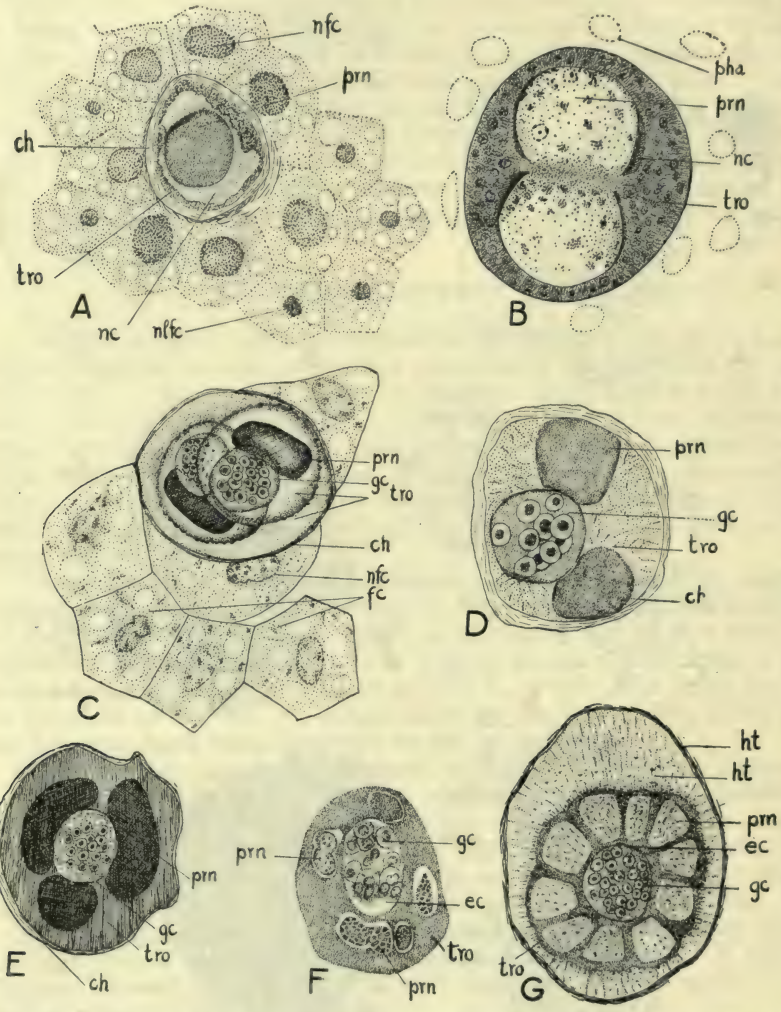


FIGURE 13.—Germs and pseudogerms of *Macrocentrus gifuensis*. A.—Pseudogerm having a paranucleus, but no germinative cells. B.—Pseudogerm with two paranuclei. C.—Two secondary germs formed from the division of a primary germ. D.—Manner of division of the paranucleus in process of encircling the germinative center. E.—Further division of the paranucleus. F.—Secondary germ, showing how the paranucleus, in the trophamnios, has surrounded the germinative center. Two paranuclei are seen dividing. G.—Secondary germ with large paranuclei

ure 13, D, E. This possibility is further supported by the fact that the writer has observed eggs of less than 5 hours of age having 13 to 30 cells and other eggs 9 hours old having only 4 to 6 cells. Thus it would seem that the egg in Figure 11, C, which is 9½ hours old, is in the first stages of transformation to a pregerm; the essential

elements of the pregerm are present, namely, two polar bodies which may unite to form the paranucleus, the germinative center of four cells, and the trophamnios or outer wall.

It is pointed out that Silvestri (*25*) has followed the early stages of segmentation of the egg of *Ageniaspis fuscicollis praysincola*, a polyembryonic chalcid, and shows that the pregerm is quite similar to that produced in *M. gifuensis*. The same author (*28*) has illustrated the early stages of *Encyrtus mayri*, which are similar to those of *A. fuscicollis*.

The next stage in the development of the pregerm is illustrated by Figure 12, D, E. These pregerms are 63 days old and were kept at temperatures varying daily from 20° to 24° C. They are of the same structure as those previously recorded, but have four or five germinative cells. Figure 12, G, represents a pregerm loose in the visceral cavity and surrounded by phagocytes. It is evidently abnormal, probably having ceased development in a stage before the germinative cells become associated in a germinative center. This pregerm might have been derived from an egg which underwent considerable segmentation during its early days, as the number of germinative cells is seen to be markedly greater than in the other pregerms. The germ in Figure 12, F, was also loose in the body cavity and is surrounded by phagocytes. Figure 12, E, is a typical example of the pregerm of this stage. Examples taken from fields September 1 and estimated to have the same age are found to be in identical stages.

The number of cells in the germinative center continues to increase by mitotic division to about 20 to 40. This stage, though differing from the pregerm only in this point, is here called primary germ in order to distinguish it from other stages. The paranucleus now divides by fission and the germinative center divides by a central constriction, forming two more or less spherical germinative centers, each accompanied by a paranuclear cell. (Fig. 13, C.) Each daughter germ thus formed is surrounded by and contained within the trophamniotic material.

This phase represents the first absolute multiplication of a preembryo which the writer has observed, and it establishes polyembryony. The two daughter germs arising from this division are here called secondary germs. Figure 13, C, is an example from field-collected material about October 1.

Following one of the secondary germs during its development it is seen that in the next stage (fig. 13, D, E, F) the paranuclear cell divides by fission (D), giving 2 paranuclei, and these in turn divide in an irregular manner giving rise to 4 or 5 paranuclei, which by remaining in the trophamnios automatically come to encircle the germinative center (F). In F two paranuclei are seen dividing while some of the germinative cells are likewise dividing.

The germinative center of the secondary germ is now composed of 30 to 40 cells and is completely surrounded by the thick trophamnios in which the large paranuclei (fig. 13, G) are embedded. As growth continues the germinative cells become more numerous, the paranuclei divide further, becoming relatively smaller, and the tro-

phamnios, which is absorbing material from the host blood, increases somewhat in thickness. (Fig. 14, C.)

When the germinative center of the secondary germs reaches that stage of growth in which it is composed of about 200 to 300 cells it again divides in two parts to form two similar germinative centers or tertiary germs contained in the same trophamnios. (Fig. 14, A.)

These germinative centers may develop to embryos or may perhaps divide once or several times in the same manner, thus producing parasite bodies containing 2, 3, 4, 5, or 6 germinative centers such as those represented in Figures 14, B, and 15, A.

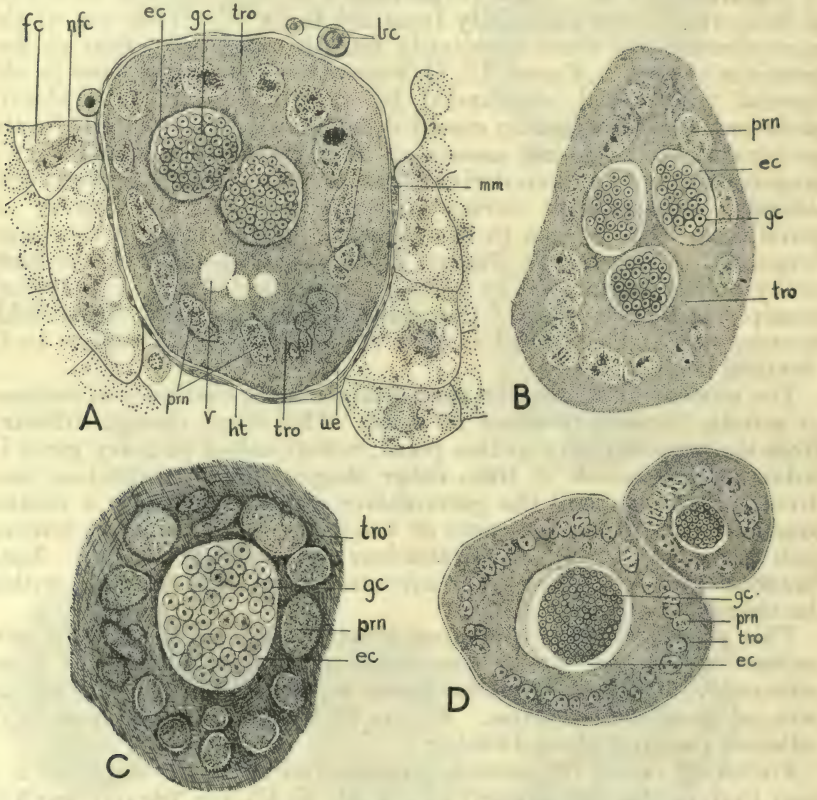


FIGURE 14.—Germs and morulae in *Macrocentrus gifuensis:* A, Secondary germ dividing to form two tertiary germs; B, a 3-morula body; C, an isolated morula; D, two morulae separating

The germs in such parasite bodies may not, however, remain together but (under the mechanical influence of the surrounding organs of the host, such as tracheal tubes, muscles, or nerve fibers, together with the general tendency of the trophamnios to enlarge and dissociate) may come apart. In this case such a dissociation is accompanied by a "flowing-in" process on the part of the paranuclei, these moving within the trophamnios and coming between the germinative centers in such a manner that each geminative center as it dissociates from the others is surrounded by the trophamnios. (Fig. 14, D.)

In the process of development from pregerm it is not known exactly how many times the division by fission takes place. It is probable that this phase of the activities varies according to the physiological condition of the host, location of the germs within the host, etc. It is even very likely that some of the pregerms do not divide at all but simply continue their growth in a regular and simple manner to produce a single morula. (Fig. 15, B, C.) However, the writer has no absolute proof of monembryony.

In the writer's opinion, morulae may be produced at any of several points along the line of development, such as from the secondary germ (fig. 13, D, G) or from the tertiary germ. (Fig. 14, A.)

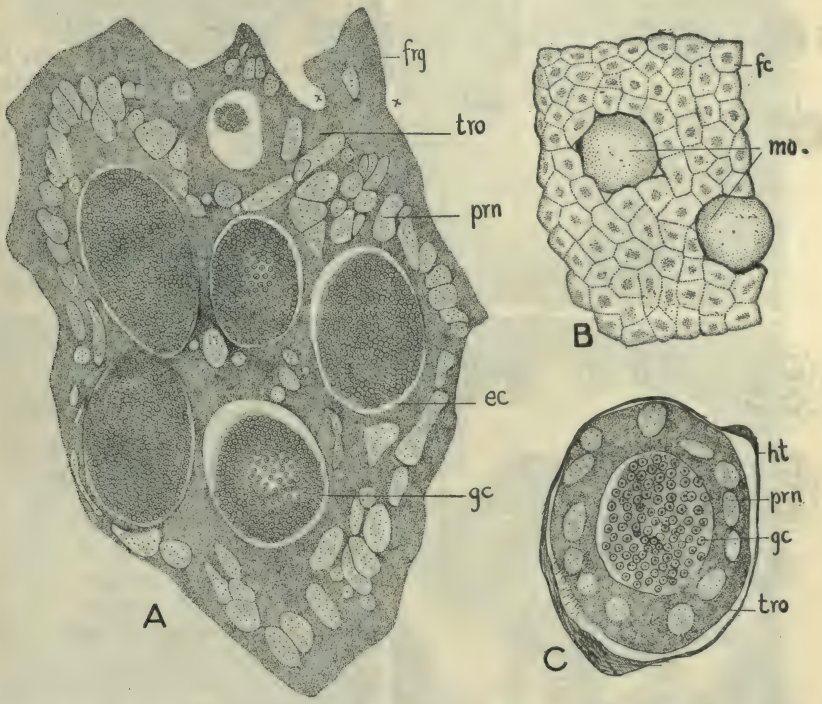


FIGURE 15.—Morulae in *Macrocentrus gifuensis:* A, A 6-morula parasite body; B, two isolated morulae in fat body; C, isolated morula surrounded by host tissue

Thus the term " morula " as used here indicates a germinative center of the types represented in Figures 14, C, D, and 15, A, C, in which no more fission will take place, i. e., each morula will produce only one larva. Under these conditions Figure 14, B, represents a 3-morula parasite body, Figure 15, A, a 6-morula parasite body, and all such bodies having more than one morula may be called polymorulae.

Figure 16 is a schematic arrangement representing the manner of growth and division of the parasite from pregerm to morula according to the writer's idea.

In general it seems that dissociation of the polymorula is the rule rather than the exception, for in host larvae containing advanced stages it is observed that the majority are simple morulae.

The morula continues its growth and after considerable increase in size transforms directly into a sort of oval disk with reflexed borders. (Fig. 17, A.) This disk by prolongation and curling becomes more slender until it has somewhat of a nematode form. Segments then begin to appear (fig. 17, E) and organs become differentiated.

At this stage the trophamnios has diminished considerably in thickness and the paranuclei are flattening out. Figure 17, B, C, shows this membrane in a degenerating condition.

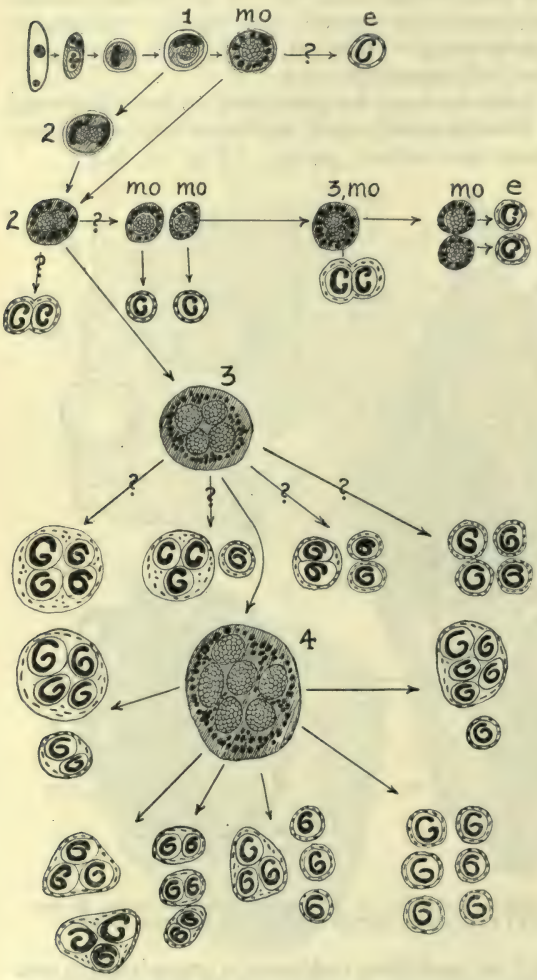
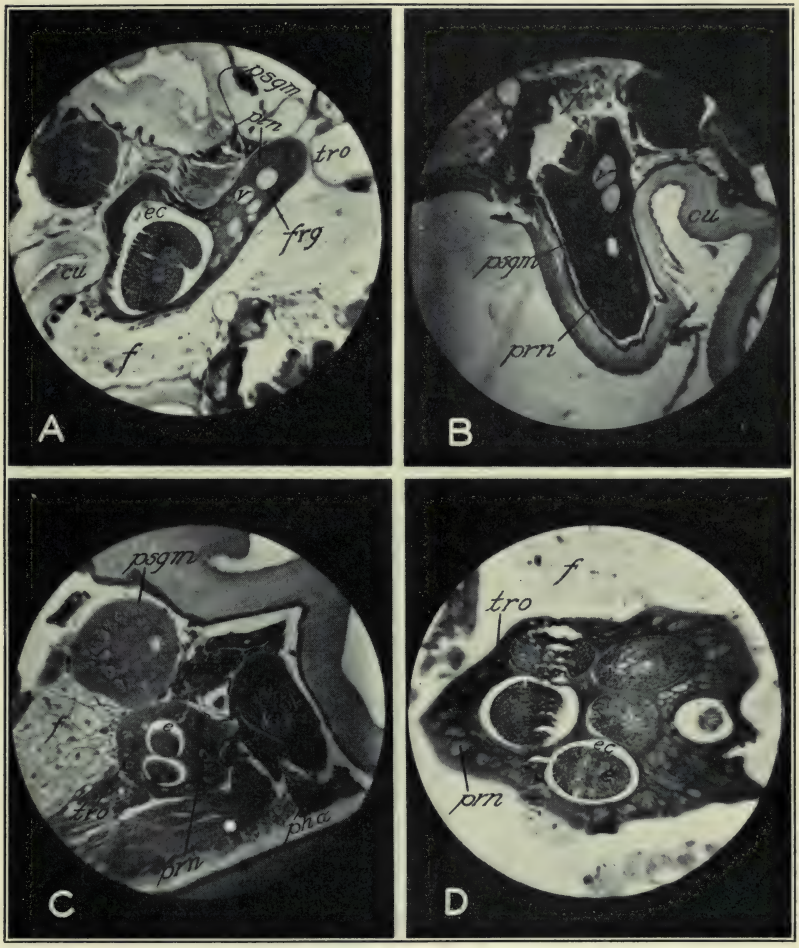


FIGURE 16.—Schematic arrangement of developing forms of *Macrocentrus gifuensis* to illustrate the method of multiplication and dissociation of germinative centers: *1*, primary germ; *2*, secondary germ; *3*, tertiary germ; *4*, quarternary germ; *mo*, morula; *e*, embryo

PSEUDOGERMS

Pseudogerms (figs. 13, A, B, 18, A, and pl. 1, C) are found in parasitized larvae simultaneously with the pregerm. They undoubtedly represent fractions of a dissociated egg which are not provided with germinative cells, or entire eggs which for some unknown reason fail to segment in the regular manner. Some of these pseudogerms are morsels of trophamnios which have dissociated from parasite bodies during their process of growth and dissociation. In Figure 15, A, for example, a piece (*frg*) is shown which will certainly break away from the main body along the line X–X, and in Plate 1, A, a simple morula is shown with a piece (*frg*) which will probably break away.

The constituents of the pseudogerm are trophamniotic material and paranuclei. No germinative cells are present as in the germs and morulae. The pseudogerms are of all sizes up to about 2 mm. in length. The smaller ones and some of the larger ones are spherical; most of the larger ones are oblong, oval, or irregular in outline. Others, as shown in Figure 18, A, are of grotesque shapes.



PHOTOMICROGRAPHS SHOWING EMBRYOS, MORULAE, AND PSEUDOGERMS IN MACROCENTRUS GIFUENSIS

A, Photomicrograph showing a single morula in a late stage of development surrounded by host organs. The piece designated *frg* will probably become detached to form a pseudogerm. The piece *psgm* has already become detached. (Bouin's, glychemalum and eosine.); B, pseudogerm or trophamniotic fragment between host organs; C, a 2-morula parasite body, a 3-morula parasite body, and a pseudogerm surrounded by host tissues; D, a greatly enlarged photomicrograph showing a section of the 6-morula parasite body illustrated in Figure 15, A. (*cu*, cuticle; *e*, embryo; *ec*, embryonic cavity; *f*, fat; *m*, muscle; *pha*, phagocytes; *prn*, paranucleus; *psgm*, pseudogerm; *frg*, fragment; *tro*, trophamnios; *v*, vacuole.)

The pseudogerms seem to grow by the absorption of nourishing material from the host and the continued division of the paranuclei. They divide by fission thus producing many smaller pseudogerms. The trophamniotic fragments derived from the parasite bodies or true morulae in the process of dissociation seem also to grow and divide.

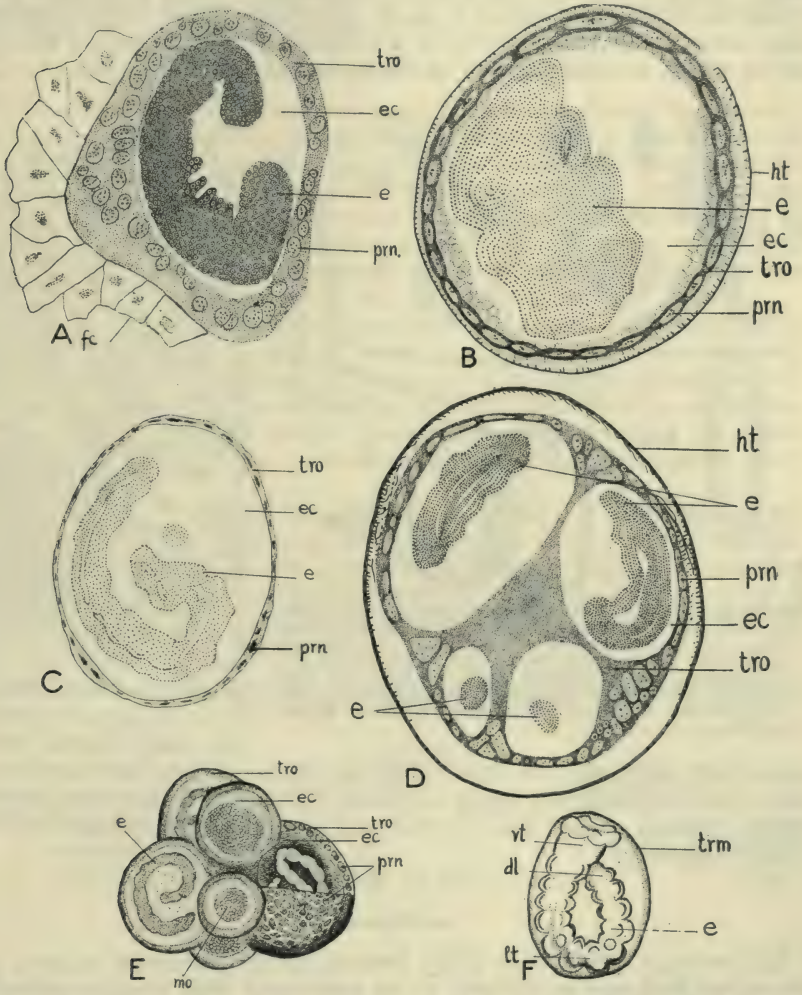


FIGURE 17.—Embryos in *Macrocentrus gifuensis:* A, Early embryo in edge of fat body; B, embryo showing degeneration of the trophamnios; C, late embryo showing further degeneration of the trophamnios; D, four embryos developing in the same parasite body; E, parasite body of three morulae and three embryos; F, late embryo

So far as the writer has been able to ascertain, no pseudogerms develop into real germs. They continue dissociation until near hatching time when large numbers of small ones having five to seven paranuclei are present. They remain in the visceral cavity and are eventually eaten by the third and fourth stage larvae.

CYST FORMATION

Certain polyembryonic chalcids (*Ageniaspis fuscicollis*, *A. testaceipes*, etc., during their development cause a definite proliferation of host tissue about the developing eggs in such a manner that all the germs arising from a single egg remain together in a single parasite body. Such is not the case with *M. gifuensis*. There is no such proliferation of the host tissue to form a nucleated cyst. The pregerm does, notwithstanding, determine a swelling of the nucleus of the fat cell in which it is lodged and of the nuclei of adjoining cells as well. (Figs. 12, A, B, C, 13, A.)

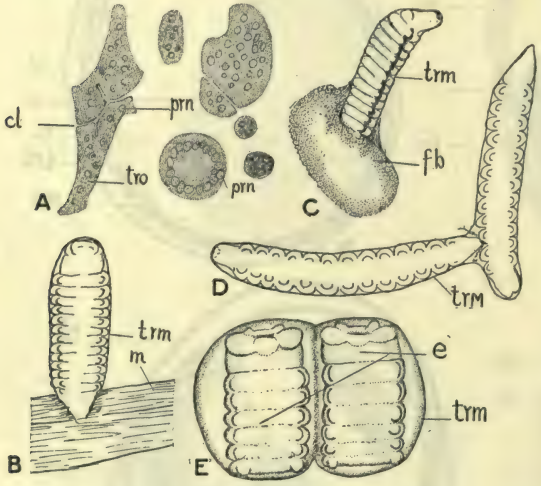


FIGURE 18.—Larvae of *Macrocentrus gifuensis* in process of hatching; A, Pseudogerms taken from host larva about the time parasites are hatching; B, hatching larva held between muscles of host by trophamnios; C, hatching larva emerging from fat body; D, two hatching larvae after unfolding, still inclosed by the trophamnios; E, two larvae in other positions before unfolding

As the germ grows the chorion is pushed outward until it coincides with the wall of the fat cell; as this takes place the nucleus of this cell is pushed to the periphery, and in turn other fat and blood cells are displaced. Their walls and contents thus form a sort of improvised cyst of mesenchymatous material around the germ or polygerm. If the germ grows to a large parasite body it will probably break out of this cyst in part or entirely, so that as development continues many germs both single and multiple are found with no tissue of any sort inclosing them, the trophamnios being in direct contact with the host blood. Others remain within this improvised cyst until the parasite larva is fully formed.

LARVAL HABITS

HATCHING

By the time the larva is fully formed the trophamnios is more or less exhausted and is reduced to an extremely thin membrane with flattened nuclei. (Fig. 17, C, *tro.*) It still retains its approximate spherical form, however, until time for eclosion, when the larva straightens out its body. This movement stretches the membrane to the length of the larva (fig. 18, B, C, D) and brings the mandibles in contact with it, thus enabling the larva to chew its way out, which it does within a few hours. Sometimes the head may be out and feeding started before the membrane is slipped completely off the body. The mid-intestine then begins to fill with fat globules and the trachea with gases, so that both organs are more easily discerned.

In cases where the larvae are fixed in the muscles or fat of the host the stretching-out process results in the anterior portion of the parasite larva being protruded while the posterior portion remains among the organs or fat where the germ was originally lodged. The larva thus seems to be fixed in this position by the anal extremity, but in reality the whole body is inclosed by the membrane. When hatching is completed the larva retains no further connection with the host organs but is free in the visceral cavity.

DESTRUCTION OF GERMS AND LARVAE

In the course of development some germs are found apparently dead and surrounded by phagocytes. Some of the smaller germs in a polymorula do not develop, probably because of their being inhibited in some way by their close proximity to larger germs.

Some embryos in the polymorula are destroyed at the moment of hatching by the earlier unfolding larvae. If the larva unfolds in such a way that there is an embryo near its mandibles, that embryo is killed by the chewing of the unfolded larva.

Often for unknown reasons (perhaps associated with mechanical injury or crowding) a single larva or a larva in a parasite body will die without unfolding. The number of larvae dying in this manner is greater in hosts bearing a large number of individuals.

The earliest hatched larvae destroy, in their feeding activities, many germs of large size as well as many hatching and some fully hatched larvae.

The data in Table 3, taken from dissections of 16 parasitized larvae made in the spring of 1929, will shed some light on the destruction of supernumerary germs and larvae. In this connection it is pointed out (as discussed elsewhere) that the average size of the male colony is 24 individuals, that of the female colony 16, and of mixed sexes 20.9.

TABLE 3.—*Data on the parasite content of 16 larvae of Pyrausta nubilalis from the field in the spring of 1928*

Larva No.	Contents									
	Number of small amniotic fragments or pseudogerms with 2 to 5 paranuclei	Number of large amniotic fragments with numerous paranuclei	Number of germs [1]			Number of larvae				
			(1) Small	(2) Middle sized	(3) Large	First stage		Second stage—alive	Third stage—alive	First, second, and third stages
						Alive	Dead			
1	10		30	20	5					
2	Many		35	25						
3	do		7	2	3					
4	do		7	7	7	45	1			
5	50	Several			7	8				
6	200	do				4	60			
7	400	12				23	6			
8	200	Several		3		21	14			
9	100	do			1	45	4			
10	40	do				21	7			
11	80	do		20		21	12	2		
12	300	20		1		31	6	15		
13	300 to 500	Several				51		70	15	
14	300 to 500	do								[2] 85
15	300 to 500	do								[2] 99
16	300 to 500	do								[2] 111

[1] These are classified approximately according to the size of the germs: (1) Secondary germs or small morulae having 5 to 100 germinative cells and 10 to 20 paranuclei, (2) morulae having 100 to 200 germinative cells and 20 to 40 paranuclei, and (3) large morulae about to transform to embryos or having already done so.

[2] In larvae Nos. 14, 15, and 16 the parasite larvae of any stage or condition were counted. Most of them were in the first stage, but no accurate separation into stages or live and dead categories was made.

These dissections were made at irregular intervals, by opening parasitized larvae in physiological salt solution and scraping out their contents. The data refer only to the material so extracted from the larvae and do not include germs and pseudogerms lodged permanently in the larval organs. In distinguishing live larvae from dead ones account was taken of a certain amount of mechanical injury incurred by the parasites during the process of removing them.

Most of the dead larvae bore signs of mechanical injury, the greater part of which was due to attack by other larvae under the crowded conditions.

It will be seen that as the season advances and larvae begin to hatch, the pseudogerms and small trophamniotic fragments become more numerous.

GROWTH AND FEEDING

The first-stage larva does no feeding until its head has issued from the embryonic membrane (the trophamnios). Shortly thereafter it begins to feed. Examinations of the stomachs of first-stage larvae show that the food absorbed is composed principally of fat globules.[12] The stomach contents are arranged in three layers. The innermost layer (fig. 5, A, *ila*), surrounded by the peritrophic membrane (*pm*), is composed of fat globules to be digested. The second layer (*ml*), outside the peritrophic membrane, consists of granular chyle of a more or less uniform consistency without or with small vacuoles; this layer is probably partially digested. The outer layer (*ol*), similar to the second in composition but somewhat thinner, probably consists of the completely digested material from which absorption takes place.

The first-stage larvae, when abundant in a host, do some chewing upon other organs, such as the muscles; occasionally (but rarely) a morsel of solid food is observed in a late first-stage larva; such morsels are observed more frequently in second-stage larvae, along with trophamniotic fragments and pseudogerms.

The second stage, lacking mandibles, can only ingest fat globules and such material as has been "prepared" by the first-stage larvae.

Third-stage larvae ingest the remaining material prepared by the first-stage larvae and probably do some gnawing and scraping on the host organs with their weak mandibles. Pseudogerms and trophamniotic fragments also constitute a part of the food of this stage.

With the completion of the third stage the larva is ready to migrate to the exterior, where it becomes an ectophage.

EMERGENCE AND EXTERNAL FEEDING

The first step necessary to emerge from the host larva is to free the head from the third-stage skin. This takes place in the following manner: The capsule splits, owing to the pressure from within, and the head of the fourth-stage larva is lifted out of it. This capsule, together with the former skin, begins to slip backwards, thus freeing the anterior portion of the body. The larva now starts the

[12] Fink (5) states that *M. ancylivora* feeds almost entirely upon "predigested food, consisting largely of lymph, body fluids, and fat globules." He cites no evidence, however, to show that body fluids and lymph are ingested. The above-mentioned materials, if absorbed, can not in any manner whatsoever be considered as predigested.

work of piercing an exit hole. It presses the mouth parts against the body wall of the host and by constant scraping with the mandibles it pierces a hole through which it thrusts its head. By continued body contortions the larva gradually squirms out, head first,[13] through the hole it has made. This process requires about one hour, and during this time the third-stage skin slips farther back on the body. As the larva completes the process of emerging it reposes for a few minutes lying on its ventral side with the hindmost segments still in the hole from which it came, then raises the posterior end slightly and brings it completely out of the exit hole, drawing with it the larval skin of the first, second, and third stages which often adhere to it. The posterior end is again brought into contact with the host skin at a point slightly distant from the exit hole so that the parasite assumes a position with its middle almost directly over the exit hole, having its shed skin or skins under the posterior half of its body and the middle and forward part of the body resting directly on the host skin. It is now in the fourth stage.

In this position the parasite rests for 15 or 20 minutes, if not disturbed by emerging larvae. After this period of repose, the larva becomes restless and manifests this condition by dorsoventral movements of its head and thorax; shortly thereafter it bends its head under the thorax, pierces another hole in the host skin near the exit hole, and fixes its mouth parts to the host at this point. In some cases, by working its body backwards, the larva applies its mouth to the exit hole, but more often a new aperture is made. External feeding then begins.

The larva sucks into its stomach the material remaining in the host's body and does not, unless disturbed, let go of its hold at the feeding puncture. If pulled away from this point, a string of material about the size of a horsehair can be seen extending from the interior of the host body into the mouth of the parasite larva. When pulled this string will come out of the host's body to a length of 1 or 2 centimeters and out of the parasite's mouth to the same length. It hardens rapidly upon exposure to the air. Microscopic examination shows it to be composed of host organs such as tracheae, bits of muscles, salivary glands, Malpighian tubes, cast skins and fragments of earlier stage parasites, pseudogerms, and the protozoan *Perezia pyrausta* Pail. which lives in the host Malpighian tubes, salivary glands, muscles, intestine walls, and oenocytes.

The parasites issue from the host at any point from the first thoracic to the ninth abdominal segments, generally at a ventral or lateral point, but sometimes dorsally. They are oriented longitudinally within the host larvae with their heads directed toward the head of the host. They lie during the external feeding period with their heads directed toward the caudal extremity of the host. After spinning, however, when ready to expel the meconium, the larvae have again reversed their position and lie with their heads toward that of the host.

These reversals in orientation are not in themselves remarkable but are only the natural positions occupied as the larva goes through

[13] Fink (5) states that the larva of *M. ancylivora* issues with the caudal extremity emerging first; the writer holds this to be improbable.

a series of mechanical movements. As the larva prepares to issue from the host it turns its venter towards the skin of the host; as it comes through the exit hole it naturally moves in a forward ventral direction and thus finds itself, when outside, lying with the venter on the host and, because it was orientated cephalad within the host, now has its head directed caudad. Had it lain originally with its head directed caudad it would have fed with its head cephalad. The peculiar feature of this phase of larval activity is the fact that the larvae are orientated cephalad inside the host before they reach the fourth stage, and this can possibly be explained in connection with the direction of circulation of the host's blood.

The second process of reversal takes place during spinning. The posterior part of the cocoon is spun first, and as it nears completion the larva reverses its position in order to complete the anterior part of the cocoon.

Thus this phenomenon is not comparable to the prepupal reversal of certain Diptera such as the Hessian fly (*Phytophaga destructor* Say) within their puparia.

When larvae issue from a host which is not in a burrow they are not orientated in any particular direction but lie mostly at right angles to the axis of the host's body. After a short rest they squirm into the most convenient position, pierce a hole, and begin feeding.

External feeding continues until the parasites are satiated if there are only a few feeding on a single host, or until the host is completely emptied. Some larvae have been observed to feed for an hour and a half and others for more than 24 hours, but these last were cases in which only a few larvae issued from the host. In a normal case, where 20 or more larvae are feeding externally on a single host, the latter is usually emptied in two or three hours. It is not, however, absolutely necessary that the larvae feed externally; if removed from the host immediately after emergence, they spin and transform in the normal manner. It is remarked in this connection that this sudden change in environment from a liquid medium to the open air, not accompanied by a radical metamorphosis, is perhaps one of the most drastic changes occurring in the life of any animal.

EFFECT OF PARASITE ON HOST LARVA

The first-stage larval feeding and chewing activities have a certain effect on the host, although this is not apparent unless closely examined, when the damage to the internal organs, more especially the fat body, can be observed. This injury is not fatal, however, for in cases where parasites die early in the first stage their presence does not prevent the host from transforming to the pupal stage. The writer has dissected apparently healthy chrysalids and found therein phagocytized first-stage Macrocentrus larvae.

The effect of second-stage larval feeding is but slightly more apparent; the host larvae seem weaker and do not move quite so rapidly as healthy ones. Host larvae containing third-stage parasites, though able to crawl, are distinctly less active than nonparasitized host larvae. Examination of the internal organs at this stage shows that the fat has been completely consumed, and the fat lobes surrounding the mid-intestine, as well as the strips lying along each side

of the dorsal vessel and the fragments between the tegumentary muscles and the body wall, resemble pieces of lacework, retaining only some of the damaged cell walls held together by fine tracheae. The muscles are sometimes attacked to such a degree that they are thin and emaciated and are not strong enough to contract the body walls in the normal manner. If there are but few parasites, the internal organs, except the fat body, are not damaged.

By the time the parasite larvae have finished the third stage the host larva can no longer crawl. As the parasites begin to emerge for external feeding, signs of life in the host diminish to a point where only a slight contraction of the abdominal and anal prolegs upon stimulation indicates that life is not extinct. The remaining internal organs previously mentioned are rapidly consumed by the external-feeding fourth-stage larvae and nothing is left of the host but the exoskeleton.

SPINNING AND PUPATION

The larvae rest quietly (after feeding) for about 24 hours, depending on the amount of food they have consumed after issuing, and then start spinning.

During the spinning the larva bends the anterior part of its body about in all directions, attaching the thread here and there. The silk which issues is a single thread, but if pulled rapidly it slips from between the prongs of the spinneret and comes out a double thread. If the larvae are placed upon a flat surface when ready to spin they are unable to form their cocoons properly, but scatter the silk over the surface in an irregular manner. After such spinning most of the larvae die before transformation to adult. In cases where for some unknown reason the silk hardens in the opening of the salivary duct (fig. 7, B), as often happens in scattered colonies, the larvae nevertheless go through all the movements and contortions of spinning, including the pauses to attach the thread. When they have continued this exercise for a considerable period of time they become quiescent as they do when inside the cocoon. Death follows for such individuals.

Each larva spins its own cocoon, and the whole group is bound together in a more or less compact mass. Individual cocoons can, however, be removed from the outer part of the mass without disturbing the others.

The cocoons are completed in about 48 hours, and when finished the larvae cease their movements and rest quietly while transformation begins. This becomes evident by the change in form of the larva; the head and thorax become somewhat distended, a slight constriction appears between the abdomen and the thorax, the eyes become visible, and the larva is unable to move except for a slight abdominal contortion. This is the prepupal stage common to all hymenopterous parasites and many other insects as well. Shortly thereafter the meconium is expelled and the change in shape becomes even more accentuated. The external appendages of the pupa soon become visible underneath the old larval skin. This skin then splits at the top of the head and slowly slips off posteriorly, revealing the white pupa with its perfect appendages.

AVERAGE SIZE OF COLONY AND PROPORTION OF SEXES

In the writer's rearing experiments, as stated elsewhere, the cocoons were conserved in vials for emergence of the adults. In order to procure data on several important points, such as the average size of the colony, the proportion dying in the cocoons, and the proportion of the sexes, careful counts were made of the adults issuing in the laboratory from 297 colonies, in the order in which these colonies issued. Of this number, 97 colonies had one or more Macrocentrus dead in the cocoons; these colonies were set aside for other studies. It was then possible to count accurately and determine the sex of all adults issuing from the remaining 200 colonies.

Among these 200 colonies, 71 gave exclusively males with an average of 24 per colony, 54 gave exclusively females with an average of 16.2 per colony, and 75 gave a mixture of males and females with an average of 20.9 per colony.

Among the 54 female colonies, 5 were composed of 1 to 5 individuals each, 8 were composed of 6 to 10 individuals each, 15 were composed of 11 to 15 individuals each, 12 were composed of 16 to 20 individuals each, 6 were composed of 21 to 25 individuals each, 5 were composed of 26 to 30 individuals each, and 3 were composed of 31 to 35 individuals each.

Among the 71 male colonies, 1 was composed of 4 individuals, 3 were composed of 6 to 10 individuals each, 6 were composed of 11 to 15 individuals each, 16 were composed of 16 to 20 individuals each, 12 were composed of 21 to 25 individuals each, 21 were composed of 26 to 30 individuals each, 6 were composed of 31 to 35 individuals each, 3 were composed of 36 to 40 individuals each, 2 were composed of 41 to 45 individuals each, and 1 was composed of 47 individuals.

From the 75 colonies producing both sexes, 840 males and 733 females issued. In order to make a more complete study of this material these colonies have been arranged (Table 4) in two different ways. In the left half they are arranged in the order of increasing number of males, and in the right half in the order of increasing number of females.

These colonies can be further divided into three groups, those in which males predominate, 41 in number; those in which females predominate, 31 in number; and those in which males and females are equal, 3 in number. These groupings, however, are not taken into account in the arrangement of the table.

TABLE 4.—*Number of male and female adults issuing from 75 mixed brood colonies of Macrocentrus gifuensis*

Ascending number of males			Ascending number of females		
Males	Females	Total	Males	Females	Total
1	2	3	4	1	5
1	21	22	6	1	7
2	5	7	15	1	16
2	37	39	18	1	19
3	14	17	1	2	3
3	16	19	6	2	8
3	33	36	11	2	13
4	1	5	29	2	31
4	18	22	32	2	34
5	3	8	5	3	8
5	8	13	8	3	11
5	12	17	11	3	14
5	13	18	15	3	18
5	17	22	23	3	26
6	1	7	21	4	25
6	2	8	2	5	7
6	6	12	8	5	13
6	9	15	9	5	14
6	11	17	13	5	18
6	13	19	14	5	19
6	15	21	20	5	25
7	6	13	6	6	12
7	13	20	7	6	13
7	14	21	14	6	20
7	16	23	15	6	21
8	3	11	16	6	22
8	5	13	17	6	23
8	8	16	20	6	26
8	8	16	25	6	31
8	9	17	12	7	19
8	15	23	14	7	21
8	18	26	22	7	29
9	5	14	5	8	13
9	15	24	8	8	16
9	15	24	8	8	16
9	22	31	11	8	19
10	13	23	13	8	21
11	2	13	15	8	23
11	3	14	17	8	25
11	8	19	6	9	15
11	12	23	8	9	17
11	16	27	13	9	22
12	7	19	15	9	24
12	10	22	20	9	29
12	11	23	12	10	22
12	16	28	19	10	29
13	5	18	6	11	17
13	8	21	12	11	23
13	9	22	5	12	17
13	19	32	11	12	23
14	5	19	5	13	18
14	6	20	6	13	19
14	7	21	7	13	20
14	16	30	10	13	23
15	1	16	18	13	31
15	3	18	3	14	17
15	6	21	7	14	21
15	8	23	6	15	21
15	9	24	8	15	23
16	6	22	9	15	24
17	6	23	9	15	24
17	8	25	3	16	19
17	16	33	7	16	23
18	1	19	11	16	27
18	13	31	12	16	28
19	10	29	14	16	30
20	5	25	17	16	33
20	6	26	5	17	22
20	9	29	4	18	22
21	4	25	8	18	26
22	7	29	13	19	32
23	3	26	1	21	22
25	6	31	9	22	31
29	2	31	3	33	36
32	2	34	2	37	39
840	733	1,573	840	733	1,573

From Table 4 it is apparent that the size of a colony is not a factor determined by the volume and mass of a single host larva considered as environment and as food supply. Consequently it must be determined by the potential power of multiplication under given conditions of the egg or eggs laid in the host. In other words, an egg can not produce as many individuals as a single host larva can successfully nourish, for if this were the case there would be but few (if any) colonies smaller than the maximum (47 for the male sex and 35 for the female sex).

As has been pointed out under the heading of larval habits, many larvae are destroyed in cases where a single host has more than 40, some are destroyed when a host bears 20 to 35 larvae of the parasite, and a few are destroyed when the colonies are less than 20. From these facts the legitimate conclusion is drawn that the number and sex of individuals issuing from a single colony do not represent the content of that colony when it was in the germ or early larval stage but represent what is left after the thinning-out process has been completed.

Leiby, after careful study (*11*), has expressed the opinion that the origin of mixed broods in *Copidosoma gelechiae*, *C truncatellum*, *Platygaster vernalis*, *P. hiemalis*, *P. variabilis*, and probably *P. felti* is explained by the depostion of two or more eggs in a single host.

The writer is of the same opinion as regards *M. gifuensis*, as he has no evidence to the contrary. If such is the case, it is quite evident that the great majority of parasitized host larvae receive two (or more) eggs,[14] not necessarily from a single thrust of the ovipositor, however.

Further examination of these figures, on the assumption that the 75 mixed colonies represent at least 150 egg depositions, shows that in 83 of these cases there were produced the average number or less than the average number (10.45) of one sex not accompanied by 10.45 of the other sex (the average for mixed brood being 20.9).

The writer concludes from the above examination, supplemented by other calculations and observations which are not included here, that the smaller colonies (6 to 10 individuals) represent more nearly the product of a single egg than do the larger ones. These conclusions are somewhat further substantiated by observations on the size of the largest polygerms and on the lingering oviposition habits of the female *M. gifuensis*.

PARTHENOGENESIS

No complete data are available to demonstrate parthenogenetic reproduction. In certain experiments, however, eggs from unfertilized females have been observed in a more or less advanced stage of segmentation. (Fig. 12, D, E.) This fact permits the supposition that this species can reproduce parthenogenetically.

[14] For if 75 larvae out of 200 received 2 eggs, 1 fertilized and 1 unfertilized, it is extremely likely that a portion of the remaining 125 received 2 fertilized or else 2 unfertilized eggs each. This holds true only if insemination is a chance process and is not controlled by the female.

CONSIDERATION OF THE ZONES IN WHICH MACROCENTRUS GIFUENSIS OCCURS

PHYSICAL CHARACTERISTICS

The Armorican zone, in which this parasite is most abundant, is a rather low region (altitude 48 meters) of rolling land, rich in pastures and cultivated lands. The principal crops are cereals, forage, and grapes.

The soil, of Jurassic and Cretaceous origin, is mostly loam and clay loam with abundant calcareo-siliceous outcroppings.

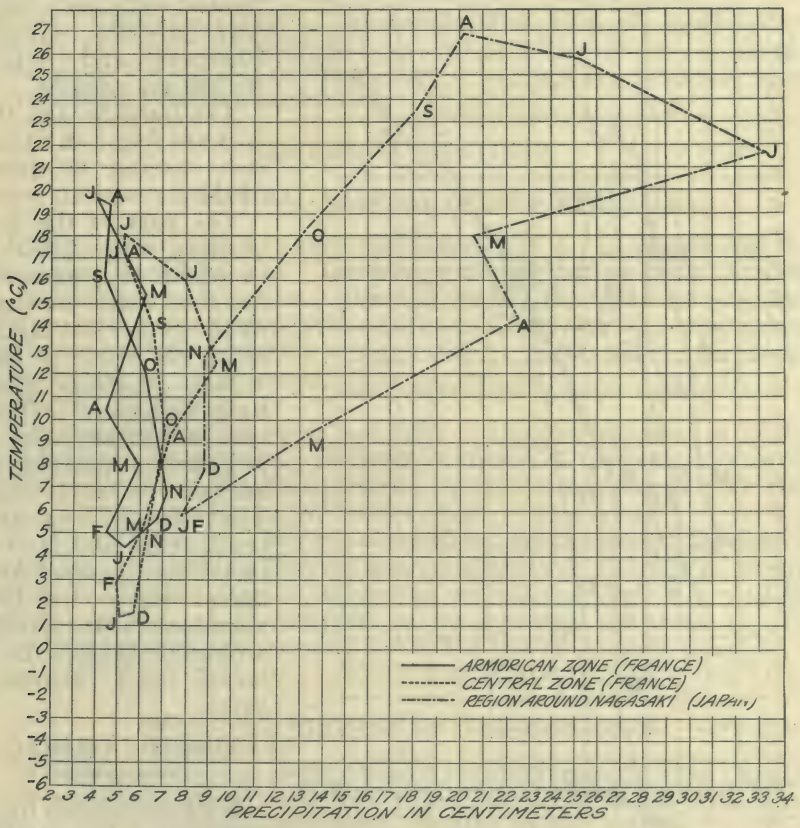


FIGURE 19.—Climographs for three zones in which *Macrocentrus gifuensis* is known to occur as a parasite of *Pyrausta nubilalis*. Letters in the graphs stand for the months of the year

Artemisia, the host plant of *P. nubilalis*, is not extremely abundant. Occasional patches and isolated plants occur in the fields and along the roads, but it is mostly confined to waste weed areas near towns, along railroad tracks, river banks, canals, and garbage dumps, and it is in such places that *P. nubilalis* and *M. gifuensis* are found.

The soil of the Central zone, in which this parasite and its host have been found (St. Etienne and Limoges), is of Presilurian and Carboniferous origin. The area is of rather limited agricultural

importance, having much of what is described as " dead " or unproductive soils. In the valleys, however, the soils are alluvial, often black from the influence of mineral-bearing strata, and are somewhat productive. In other parts the soils formed by the decomposition of schists and sandstones to a considerable depth support pastures and meadows, and when sufficiently treated with lime they will produce cereals. Chestnut and other forests are present.

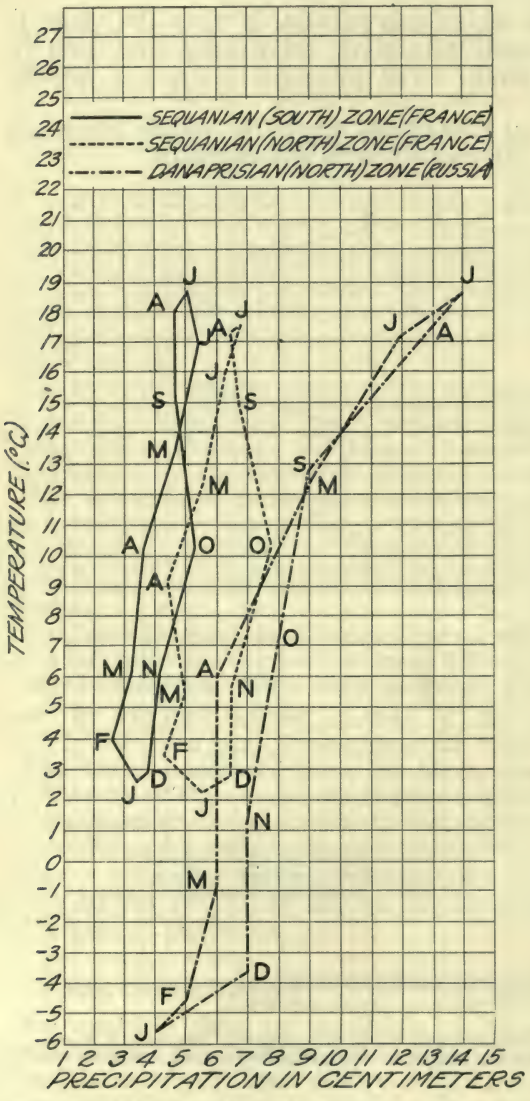


FIGURE 20.—Climographs for two zones in which *Macrocentrus gifuensis* is known to occur as a parasite of *Pyrausta nubilalis* and one in which it does not occur. *M. gifuensis* does not occur in the Sequanian (north) zone. Letters in the graphs stand for the months of the year

The parasite and its host are found in situations similar to those of the Armorican zone.

The part of the Sequanian zone (south) in which this parasite has been found consists of the rather flat lands along the Seine in the vicinity of Paris (altitude 60 meters). The soil, of Tertiary origin, is a fertile marlaceous and calcareous clay soil. The principal crops are truck crops and fruits, including grapes. Artemisia abounds in the abundant waste lands around the dumps, factories, and railroad yards.

CLIMATIC CHARACTERISTICS

With the present limited knowledge of the distribution and hosts of *M. gifuensis* it is impossible to discuss the climatic characteristics comprehensively. The climographs (figs. 19 and 20) for the Armorican, Central, Sequanian, and Danaprisian zones, and for the region of Kumomoto (based on data from Nagasaki), show the general characteristics of the climates in which *M. gifuensis* occurs.

The most important fact shown by the climographs is that *M. gifuensis* occurs and apparently flourishes as a parasite of *P. nubilalis* under a variety of conditions, ranging from approximately the continental type of climate with warm summers and extremely cold winters to the climate with warm winters and hot summers accompanied by excessive rainfall, as represented by Nagasaki. None of the zones in which *M. gifuensis* occurs has a hot, dry summer.

While the nonoccurrence of *M. gifuensis* in zones having hot, dry summers may possibly be ascribed to the apparently unfavorable climate prevalent there, its nonexistence in other and more favorable zones, such as, for example, the Sequanian (north) zone, the Jura region (Rhodanian zone), the Aquitainian zone of southwestern France, and the Po Valley of Italy, can not be explained upon this basis, since the climate in these zones is between the extremes where this parasite is known to flourish.

SEASONAL HISTORY

SEASONAL HISTORY OF THE HOST

Pyrausta nubilalis has only one generation in the Armorican and Sequanian (south) zones. The overwintering larvae start pupating in early May and continue through June; the peak of pupation occurs during the latter half of June. Eggs are laid throughout the latter half of June and through July. The resulting larvae are fully developed, have ceased feeding, and have gone into diapause by the last of August.

The seasonal history of *P. nubilalis* in the Central zone is similar to that in the Armorican. Nothing is known of the seasonal history of *P. nubilalis* in the Danaprisian (north) zone, except that full-grown larvae were found in October, 1929, in this zone.

In Japan[15] it seems that there are three generations of the host in the region where *M. gifuensis* is most abundant. The first generation and the early part of the second coincide more or less with the seasonal history of *P. nubilalis* in its 2-generation areas (*2*, *29*). The second generation pupated about the last of August, thus giving rise to the third generation, which overwinters in the larval stage.

SEASONAL HISTORY OF THE PARASITE

As is demonstrated in Figure 21, the seasonal history of the parasite synchronizes extremely well with that of the host in the Armorican zone, where it has been intensively studied by the writer.

The peak of adult emergence occurs during the latter part of June and the majority of the eggs are deposited during the first half of July. The segmentation and development of the egg take place rather slowly. In the first half of September the tiny spherical pregerms (fig. 12 B, C) are abundant; as the autumn advances a considerable number of primary and a few secondary germs appear;

[15] It will be necessary to await the results of studies now being made by W. B. Cartwright before definite conclusions can be drawn in regard to *M. gifuensis* in areas having two or three generations. The above is mentioned as a caution against erroneous conclusions likely to be made when the European zones alone are considered.

these are the stages most common during the winter. (Figs. 12, E, 13, D–G.) In early spring the growth and division are intensified and proceed rapidly. About February 1 the parasites are in the late germ and small morula stages. From this time on to the middle of March the smaller secondary germs increase in size, while the tertiary germs and small morulae grow into embryos. During the latter part of March the germs in a host larva can be classed roughly into three more or less distinct groups.[16]

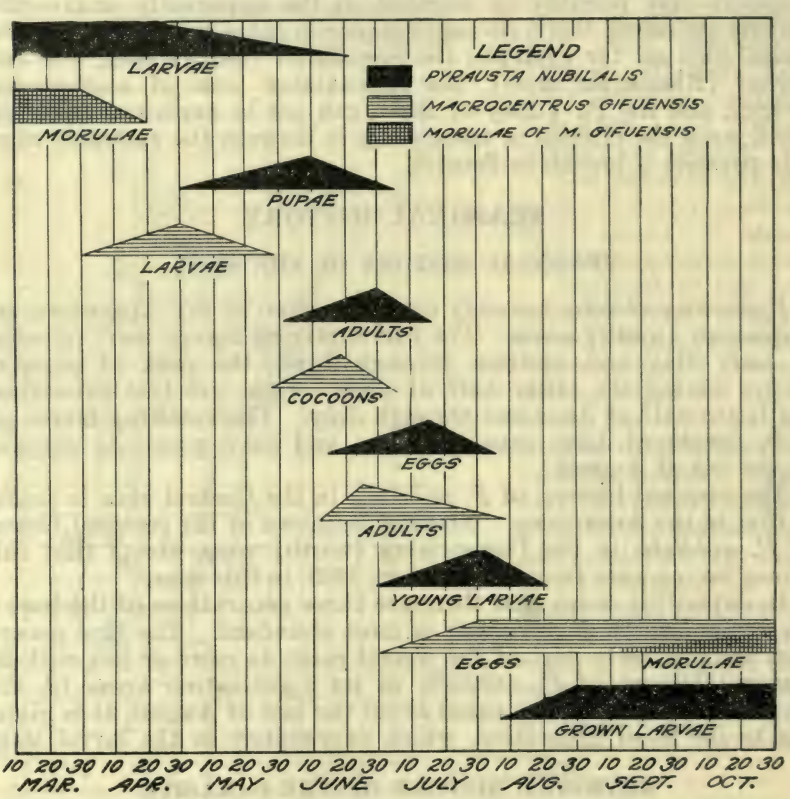


FIGURE 21.—Seasonal activities of *Pyrausta nubilalis* and its parasite, *Macrocentrus gifuensis*, as determined from field observations associated with laboratory rearings. The extremes of each area represent approximately the earliest and latest activities while the apex represents the peak of such activities

The first group (1) (fig. 13, G) consists of germs in an early stage of growth—perhaps late secondary germs or early morulae measuring about 0.1 to 0.2 mm. in diameter and having a relatively thick trophamnios with 10 to 20 paranuclei and a central group of perhaps a hundred germinative cells. The second group (2) is composed of morulae 0.2 to 0.5 mm. in diameter, of the same fundamental structure as those of group (1) but having a thinner trophamnios, more paranuclei, and a larger central group of germinative cells. The third group (3) (fig. 13, A, B, C) is composed of

[16] In tables setting forth experimental data these groups will be designated by (1), (2), and (3).

large secondary germs, 0.5 to 1 mm. in diameter, in which the embryo is forming and the germinative cells are arranged in a slender curled filament in the embryonic cavity (E).

The majority of the germs are single, but many polymorulae of from two to six germs are present. Often, with the dissecting needles, it is possible to separate two germs which seem united in a single parasite body; in other cases it is impossible. The writer believes that in cases where germs are easily separated in this manner they are about to come apart in the natural process of growth and division by fission.

Germs in the same parasite body are in the same or almost the same stage of development. In Figure 17, E, six germs are represented, three of which are in the early embryo stage and three of which are morulae.

In addition to the above groups of true germs, there are found in every parasitized larva at the same time large numbers of pseudogerms or trophamniotic fragments (fig. 18, A), as described elsewhere. In a single parasitized larva there may be more than a thousand of these fragments and in most cases there are several hundred.

The larger parasite bodies are free within the body cavity; the single morula is found free or lodged in or between organs such as fat cells or muscles. The majority of all forms are found in the posterior part of the host's body. They probably are lodged in this portion of the host because of the blood flow.

By the first of April hatching has started. The date of maximum occurrence of first-stage larvae is about the last of April. Growing larvae are then present until the latter part of May, when cocoons begin to appear. The maximum pupation occurs about June 5 to 10.

Data from the Danaprisian (north) zone are somewhat meager. Host larvae received at Hyères in November, 1928, gave, by dissection, late germs, early embryos, and first-stage larvae of *M. gifuensis*—a condition corresponding to the development of about April 1 in the Armorican zone. It is probable that, on account of the long cold winters and the more decisive and abrupt changes from one season to another, the development of *M. gifuensis* proceeds more rapidly in spring and summer in that zone than it does in regions having a more equable climate. This might explain the different seasonal rhythm of the parasite in this zone.

In Japan (Kumomoto, Miyazaki, Shizuoka) Cartwright has reared this species to the adult stage from July to November, the majority emerging in July, a considerable number during the first half of August, and scattering colonies from that time until the last of October. It is probable that the high temperature and humidity prevailing in Japan during the summer months are responsible for two (or more) generations per year.

EXPERIMENTAL DATA

In that portion of this bulletin which deals with experimental data the writer has sought to avoid lengthy tables. There are, however, several phases of the investigations which can best be presented in tabular form.

Although certain of these tables may seem to resemble others in some points, this is in reality not true, as each one is presented in order to demonstrate a certain limited phase of the activities of *M. gifuensis*.

LABORATORY BREEDING EXPERIMENTS

The writer conducted a series of experiments on the earlier stages of development of the egg in order to determine the rapidity of development. In all, 420 host larvae were isolated and exposed to gravid females in the manner described under Technic (p. 6). Of the parasitized larvae, some died, probably from superparasitism and some from unknown causes; a great number pupated before the parasite egg had time to develop; and others, after a period of incubation, were found to be in a poor physiological condition [17] with no live parasites present.

When sectioned, about a dozen larvae were found to be parasitized.

After 36 days at 18° C. the eggs were found to be in the pregerm stage of development, and after 43 days they were but slightly further advanced.

At 22° C., after 63 days, they were found to be in the stages represented by Figure 13, D–G, some having two paranuclei with 6 to 10 germinative cells (primary germs), others having 8 to 10 paranuclei with a center of 20 to 30 germinative cells (large primary or secondary germs).

The above data are taken from eggs laid by both fertilized and unfertilized females and coincide with stages of development found in larvae taken from the field on August 29 and estimated to be about two months old.

No colonies were brought through to maturity from laboratory-deposited eggs.

MORTALITY IN REARING OF FIELD MATERIAL

The necessary colonies of parasites for study, experimentation and reproduction, determination of extent of parasitism, proportion of sexes, etc., were procured by bringing parasitized larvae from the fields and rearing them in incubators at 18°, 20°, and 25° C., and in the outdoor insectary at normal temperatures. The method of handling the larvae and the cocoons is described under Technic (p. 6).

Following is the summary of total rearings in all the different experiments taken as a whole, carried on by the writer in the winter and spring of 1928–29.

	Number	Per cent
Total host larvae in experiments	3,247	100
Died	768	23.6
Pupated	1,788	76.4
Gave colonies of M. gifuensis	691	

[17] These larvae were characterized by several distinct phenomena. (1) The fat body was poorly developed, the fat cells and their nuclei being easily distinguished under low-power magnification because of a lack of fat globules; (2) hundreds of small black spots were present throughout the fat body; (3) the fat usually surrounding the heart and reproductive organs was entirely absent; (4) the pericardial cells were enormously developed. The larvae were also heavily parasitized by the protozoan *Perezia pyraustæ* Pail., which was present in the salivary glands, Malpighian tubes, walls of the mid-intestine, and muscles. It seems to the writer that these protozoa must have interfered considerably with the metabolic activities of the host larvae.

SUMMARY OF DURATION OF VARIOUS STAGES

The approximate length of the various stages from the time of emergence of the parasite from the host larva to the time of adult emergence is given in Table 5, and a summary of the longevity of adults when provided with food and moisture is given in Table 6. Adults of both sexes, when left without liquids such as sweetened or plain water, died within two or three days.

TABLE 5.—*Summary of approximate length of various stages of Macrocentrus gifuensis after emergence from the host larva*

Temperature	External feeding stage	Spinning stage	Resting stage	Pupal stage	From emergence from host to transformation to adult
	Day	*Days*	*Days*	*Days*	*Days*
27° C.	¼–½	1	1	8	10½
25° C.	½	1½	1	10	13
20° C.	¾	2½	1¾	16	21
18° C.	¾	2½	1¾	17	22

TABLE 6.—*Summary of length of life (in days) of adults of Macrocentrus gifuensis with food and moisture*

Inclosure	Temperature	Sex	Individuals	Average longevity	Maximum for a single individual
	° *C.*		*Number*	*Days*	*Days*
Laboratory	16–24	Males	5	15.4	23
Do	16–24	Fertilized females	21	16.7	30
Refrigerator (constant)	18	do	27	17.7	36
Do	18	Unfertilized females	19	13.8	21
Do	4	do	14	16.0	20

RAPIDITY OF SPRING DEVELOPMENT

The following experiments were planned to show the influence of temperature and moisture upon the rapidity of spring development of the parasite under different conditions. The host larvae, containing parasite germs and embryos, were collected in the field and immediately placed in incubators. Certain boxes were kept dry and others were supplied abundantly with contact moisture by plunging in water at regular intervals. Table 7 gives the results of these experiments.

TABLE 7.—*Rapidity of spring development of Macrocentrus gifuensis under different conditions and synchronization of parasite metabolism with that of host under favorable conditions*

Laboratory No.	Date collected from field	Approximate stage of parasite development [1]				Temperature at which exposed	Moisture	Pyrausta nubilalis in lot	Hosts died	Parasitism in lot [2]	Colonies of M. gifuensis developed	Chrysalids formed	Average time from beginning of experiment to—	
		Germs			Larvae								Spinning of cocoon	Pupation of host
		(1)	(2)	(3)										
	1929					°C.		*Number*	*No.*	*P. ct.*	*No.*	*No.*	*Days*	*Days*
3098	Mar. 25	----	1	5	1	18	Wet	102	7	40	38	57	43	45
3097	do	----	1	5	1	18	Dry	76	69	40	3	4	74	97
3050	Feb. 8	10	3	1	-----	20	Wet	181	27	30	47	107	45	39
3051														
3053A	Feb. 22	7	2	1	-----	20	do	103	8	9	4	91	38	33
3090	Mar. 26	----	1	5	1	20	do	153	35	20	24	84	38	34
3091														
3053C	Feb. 22	7	2	1	-----	20	Dry	92	69	9	2	21	68	69
3033	Feb. 26	7	2	1	-----	25	Wet	308	42	10	24	236	24	30
3034														
3053B														
3088	Mar. 26	----	1	5	1	25	do	205	53	24	37	115	23	24
3089														
3030	Feb. 8	10	3	1	-----	25	Dry	59	52	52	[3] 7	0	32	-------

[1] (1) indicates small germs, (2) medium-sized germs, and (3) late morulae or early embryos. For more exact description of these stages see Seasonal History, p. 49. The figures in the columns under this heading indicate the proportion of these various stages present on this date.

[2] As determined independently of the experiment.

[3] Small colonies all; total of 27 individuals for 7 colonies equals 3.8 per colony, whereas the norma colony is about 20.

The experiments just described demonstrate very clearly two important facts; (1) under favorable conditions the seasonal rhythm of the parasite is closely synchronized with that of the host; and (2) contact moisture for the host larva is a necessary factor in the development of the parasite, for without it many colonies die without emerging from the host, and those colonies that do develop are often small and unhealthy and usually die before transformation.

It is amply demonstrated by these experiments that moisture plays an important part in the development of *M. gifuensis*. K. W. Babcock has pointed out that the host larva, after hibernation is completed, must have plenty of contact moisture in order to transform successfully. This requirement is also necessary for the development of the parasite. It would seem that, bathed as it is in the blood of the host, the parasite might be able to develop successfully whether or not the host is able to do so. This is not so, however, as the experiments showed. Parasite germs in host larvae brought from the field in fall or winter, when exposed to high temperature with sufficient contact moisture, developed rapidly,[18] whereas those placed at the same temperature without contact moisture nearly all died, and the few that developed did so in an abnormal manner and often furnished small unhealthy colonies. It is probable that the concentrated condition of the host's blood—when it has undergone a period of anhydrobiosis—reacts unfavorably on the parasite germs and young larvae and prevents them from developing normally.

It would appear that the moisture requirement is not so great as the parasite develops into the second and third stage larva: and it is

[18] The hosts, however, do not come out of their winter lethargy so readily in the fall or early winter as the parasites.

certain that the parasites may emerge from the host, spin their cocoons, and transform to adults under comparatively dry conditions. In fact, cocoons spun without contact moisture gave in general better emergence that those spun under wet surroundings.

On the other hand, the adults seem to live longer in a moist atmosphere than in a dry one (see p. 53).

MORTALITY IN THE PREPUPAL AND PUPAL STAGES

Under the method of rearing already described, the mortality in the cocoon stage under normal conditions was comparatively low. In a total of 297 colonies observed for this purpose, 200 colonies had no dead, while 97 colonies had one or more individuals dead in the late larval, prepupal, pupal, or adult stage. Adults to the number of 6,480 issued in good condition, while 691 individuals (or but slightly over 2 per colony) were found dead in the 97 colonies of cocoons. These rearings were made at temperatures of 18°, 20°, and 25° C., and the results approximate those obtained by field observations (see Limiting Factors, p. 57).

COLD STORAGE OF OVERWINTERING HOST LARVAE CONTAINING PARASITES

This experiment was undertaken in order to ascertain the possible effect of low temperature on the earlier stages of Macrocentrus. It applies to the late stages of the segmented egg,[19] i. e., secondary germs and early embryos, and was conducted in the following manner:

Larvae were collected in the field weekly, in lots of about 200, from February 1 to March 29, and placed in corrugated paper in metal shipping cans. They were immediately soaked by plunging the entire can in water, drained thoroughly, and placed in a constant-temperature refrigerator at 4° C. Once during the experiment the cans were removed from the refrigerator, soaked thoroughly by dipping, drained for 24 hours, and replaced. On June 24 all were taken from the refrigerator and, after removal of the dead larvae, were soaked, drained for 24 hours, and placed at 25° C.

When examined on July 9, a total of 130 colonies had issued from the host larvae and were spinning or had spun, while 136 colonies (as shown by dissection) in the second and third stages and one colony in the first stage were feeding internally.

Those consignments exposed to a temperature of 4° C. for nearly five months did not differ materially, in the percentages of parasites and chrysalids eventually produced, from those lots which were kept at 4° C. for about three months.

The following figures summarize the data in this experiment:

	Number	Per cent	Per cent
Larvae of P. nubilalis in experiment	1,443	100	
Dead at end of cold-storage period	102	7.1	27
Died during latter part of experiment	288	19.9	
Pupated	655	45.4	73
Furnishing healthy parasite colonies	268	18.6	
Healthy larvae (unparasitized) dissected at end of experiment	130	9.0	

[19] For further data on the stages of development during this period see Seasonal History, p. 49.

Thus it will be seen from this experiment that cold storage at 4° C. can be tolerated by both parasite and host, when supplied with moisture at intervals to prevent desiccation, for a period of three to five months, and it will probably be found that they can tolerate such storage conditions for a much longer period.[20]

The importance of the above data in the handling and colonization of *M. gifuensis* is evident, when the manipulation of the parasite and synchronization of liberations with desirable field conditions is considered.

COLD STORAGE OF COCOONS

Data relating to cocoons kept in cold storage are presented in Table 8.

TABLE 8.—*Data on cocoons of Macrocentrus gifuensis kept in cold storage for different periods in 1929*

Number of colonies in experiment	Estimated number of individuals	Date placed in cold storage	Condition at start of experiment	Temperature	Date removed	Total time in cold storage	Temperature at which exposed subsequently [1]	Number of adults issuing	
								Males	Females
				° C.		Days	° C.		
7	140	Apr. 22	Prepupae and early pupae	4	June 1	40	18	6	0
6	120	May 15	Late larvae completely spun.	4	May 31	16	25	3	20
9	180	do	Prepupae and early pupae	4	do	16	25	44	[2] 22
3	60	May 7	do	4	do	24	25	0	2
5	100	do	Late larvae all spun	4	do	24	25	0	0
6	120	Apr. 30	Prepupae and early pupae	4	do	31	25	0	0
8	160	Apr. 8	Spinning larvae	4	June 7 [3]	60	25	[3] 0	[3] 0
9	180	do	Completely spun larvae and prepupae	4	do [3]	60	25	[3] 0	[3] 0

[1] Warmed up slowly.
[2] Females had ovipositors curled and were generally in poor condition.
[3] Many dead were noted on June 7, when removed from cold storage.

Thus it is evident from these experiments that the late larval and pupal stages of this species can not well tolerate exposure to low temperature, even for so short a period as 16 days. This method can not therefore be utilized in the manipulation and colonization of this parasite.

MACROCENTRUS GIFUENSIS AS A CONTROLLING FACTOR OF PYRAUSTA NUBILALIS

This parasite appears to be of considerable importance as a controlling factor in the limited areas in which it attacks *P. nubilalis*. Table 9 shows the extent of parasitism by this species.

[20] Other material placed in cold storage at the same time was furnishing normal colonies in abundance on Oct. 25, 1929, when these pages were being written.

TABLE 9.—*Percentages of parasitism of Pyrausta nubilalis by Macrocentrus gifuensis in various zones*

Year	Armorican zone (in Artemisia)		Central zone (in Artemisia)		Sequanian zone (in Artemisia)		Danaprisian (north) zone (in corn)	
	Hosts studied	Parasitism	Hosts studied	Parasitism	Hosts studied	Parasitism	Hosts studied	Parasitism
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
1924	1,000	8.9						
1925	212	[1] 35.3				0.01		
1926	296	33.3				.01		
1927	735	36.2	242	22.7	1,000	2.0		
1928	3,481	[1] 26.8	575	7.1	1,266	.6	80	24
1929	440	20.0	558	39.7	1,326	1.7		

[1] Additional data obtained from dissections and rearings since the publication of earlier data on this subject (*29*).

LIMITING FACTORS

The principal item which limits the efficiency of *M. gifuensis* as a controlling factor of *P. nubilalis* is, in the writer's opinion, the inability of the female to locate and sting the host larva. The reactions of the female in this connection have been described under Oviposition, page 25. The writer ventures to say that in all probability nine-tenths of the eggs which the female is capable of producing are never deposited.

Mutual destruction among the first-stage larvae and the destruction of some large germs and embryos reduce somewhat the size of the colonies developing in a single host. It must be pointed out, however, that, as this destruction is greater when the host larva bears many more parasites than it can nourish and negligible when the size of the colony is below the average, this factor is not very significant.

Mortality in the cocoon stage is not exceptionally high. In 35 colonies collected in the field, 17 had no dead pupae or adults while 18 colonies had 50 dead individuals. Experimental results (see p. 55) with 297 colonies closely approximate these figures.

No hyperparasites have been observed in colonies collected from the field.

RECOMMENDATIONS

It appears to the writer that the methods of rearing and colonization which would allow the optimum opportunity for establishment and dispersion of the parasite would be a system which envisages the following two principal points: (1) The liberation of material from 1-generation areas (Europe) in 1-generation areas, while the 2-generation areas would be supplied from material originating in 2-generation areas. (2) The most profuse liberations of the parasite should coincide with or precede but slightly the maximum abundance of second and third stage host larvae of the overwintering generation.

In order better to accomplish the latter recommendation, it will be found practicable to retard the spring development and emergence of imported material by cold storage. The acceleration of develop-

ment can be started at a suitable period in advance of the appearance of young host larvae.[21]

In this way the parasite would have a better chance to establish itself in numbers in larvae which overwinter, whereas, if liberated coincident with the appearance of larvae of the first generation, many eggs, owing to their slow rate of development, would be lost through the midsummer pupation of these larvae. Thus the number of parasites likely to pass the first winter successfully would depend upon the small proportion of host larvae of the first generation which failed to pupate in summer, and upon the number of *M. gifuensis*, if any, able to develop and issue before their first-generation hosts had pupated.[22]

It is not considered advisable to retard the importation and colonization of *M. gifuensis* and other parasites in order to make ecological studies. On the contrary, no time should be lost in importing this parasite and liberating it at all strategic points which present considerable easily determined variations in physical and climatic characteristics, provided that such points are well supplied with acceptable hosts. It is inadvisable to liberate the parasite in advance of the borer spread.

SUMMARY

Macrocentrus gifuensis Ashm. is a primary parasite of *Pyrausta nubilalis* Hübn. in France, Russia, and Japan. It has been reared from this host taken in Artemisia, corn, and hemp.

It does not occur as a parasite of *P. nubilalis* in the principal corn regions of Europe. For this reason its economic importance seems at first glance negligible. The percentage of parasitism in the weed (Artemisia) areas of the Armorican zone of France has, however, maintained itself around 30 per cent for several years; it is thus seen that this parasite is a factor which can not be neglected in the fight against the corn borer.

The eggs of the parasite are laid in the body cavity of young host larvae during the latter part of June and in early July. Development is by polyembryony, a method of development not before recorded in the Braconidae.

The egg, in the writer's opinion, transforms to a tiny spherical pregerm, containing a huge paranuclear cell formed from the polar bodies and a small group (generally two to six) of embryonic cells derived from the cleavage nucleus and contained within the ooplasm of the egg and polar bodies, i. e., the trophamnios. The whole is encircled by a thick chorion. The pregerm is usually lodged in a fat cell.

The pregerm grows to a primary germ by the mitotic division of the embryonic cells, and this primary germ divides by fission. The paranuclear cell divides also, half of it accompanying each half of the germinative center, thus forming two secondary germs, each of which is similar to the primary germ.

[21] From the moment of removal from cold storage to the appearance of the adults, 34 days at 25° C. are required, 54 days at 20°, and 60 days at 18°, provided the material is given thorough soakings accompanied by alternate dryings.

[22] D. W. Jones has reared this parasite from egg to adult. The minimum time required for development from the egg to full-grown larval stage was 14 days. This fact is cited here in order to stress the hypothesis that studies made on an insect in its native home can not be taken as an absolute guide to what that insect will do in a new environment. This is true for the parasite as well as for the host.

The paranucleus of the secondary germ now divides several times until its cells encircle completely the germinative center of embryonic cells.

The embryonic cells continue their multiplication and the germinative center again divides to form two tertiary germs, both inclosed within the trophamnios.

This process may be repeated several times and the resulting germinative centers may remain together or separate entirely or in part, thus forming isolated morulae, or parasite bodies containing from two to six morulae.

Pseudogerms or trophamniotic morsels, similar to the true germs except that they have no embryonic cells, are present and grow and divide to form hundreds of smaller ones. These pseudogerms do not develop into larvae but are eaten later by the parasites.

There is no blastula stage. The morula changes into an oval disk with reflexed borders and this develops into a slender, curled embryo which forms the larva.

The trophamnios degenerates into an extremely thin membrane with flattened nuclei.

There is no proliferation of host tissue to form a cyst as in *Encyrtus fuscicollis* Dalm.

The larvae gnaw their way out and in so doing they destroy some other larvae and germs.

Hatching takes place in April. The first-stage larva has a head and 13 segments, a pair of sharp mandibles, four rows of enormous lobes resembling pseudopods, and an evaginated rectum. The peculiarities of its internal anatomy are the unequal lengths of the two Malpighian tubes and the distinct division of the hind-intestine into ileo-colon and rectum. No spiracles are present, though a tracheal system is developed.

The first-stage larvae feed mostly on fat globules. The second and third stage larvae feed internally but the fourth stage issues from the host and feeds externally.

The second-stage larva has no mandibles, the third has thin, weak ones, but the fourth stage has strong, toothed mandibles. No spiracles or tegumentary spines are present on the first and second stages but the fourth-stage larva is covered with tiny spines and has nine pairs of open spiracles.

Within the host, the larvae lie with their heads towards that of the host. As they issue, however, they reverse their position and accomplish external feeding orientated in a caudal direction. While spinning, the position is again reversed so that the pupa is orientated cephalad. These orientations are the natural result of a series of mechanical gyrations accomplished in a certain manner.

Pupation takes place about the middle of June and adult emergence towards the latter part of June.

The ovipositing female generally lays one egg at one thrust, though sometimes perhaps two or three may thus be laid.

Most parasitized larvae contain several eggs because of the "repeating" habits of the females when ovipositing. As a result there are usually many more larvae and germs of the parasite present in the host larva than it can nourish. The supernumerary germs or larvae are destroyed during feeding and growth.

In these studies the average size of a colony was 24 if all males, 16 if all females, and 20.9 if sexes were mixed; 37.5 per cent of the colonies were mixed broods. The maximum number of individuals developing from a single egg is believed to be 8 or 10.

The mortality in the laboratory rearings of field-collected host material was 23.6 per cent, exclusive of those killed by parasites.

The average length of life of females was 17.6 days and the maximum was 36 days when supplied with sweetened or honey water for food.

Contact moisture for the host in the spring is necessary for the development of the parasite, otherwise it will die or produce small, unhealthy colonies.

The time required to complete development from early spring to the adult stage is 34 days at 25° C., 54 days at 20°C., and 60 days at 18° C. These temperatures should be accompanied by alternate soakings and dryings of the host material.

Parasites in overwintering host larvae may be retarded by cold storage for as much as four months or more after their normal emergence time. Cold storage will kill the late larvae and pupae, however.

LITERATURE CITED

(1) ASHMEAD, W. H.
1906. DESCRIPTIONS OF NEW HYMENOPTERA FROM JAPAN. U. S. Natl. Mus. Proc. 30: 169–201, illus.

(2) CAFFREY, D. J., and WORTHLEY, L. H.
1927. A PROGRESS REPORT ON THE INVESTIGATIONS OF THE EUROPEAN CORN BORER. U. S. Dept. Agr. Bul. 1476, 154 p., illus.

(3) CUSHMAN, R. A.
1913. BIOLOGICAL NOTES ON A FEW RARE OR LITTLE KNOWN HYMENOPTERA. Ent. Soc. Wash. Proc. 15: 153–160, illus.

(4) FERRIÈRE, C.
1926. NOTE SUR UN CHALCIDIEN À DÉVELOPPEMENT POLYEMBRYONIQUE. Rev. Suisse Zool. 33: 585–596, illus.

(5) FINK, D. E.
1926. THE BIOLOGY OF MACROCENTRUS ANCYLVORA ROHWER, AN IMPORTANT PARASITE OF THE STRAWBERRY LEAF ROLLER (ANCYLIS COMPTANA FROEHL.). Jour. Agr. Research 32: 1121–1134, illus.

(6) GENIEYS, P.
1925. HABROBRACON BREVICORNIS WESM. Ann. Ent. Soc. Amer. 18: 143–202, illus.

(7) HERGULA, B.
1929. INSECT PARASITES OF THE CORN BORER IN NORTHERN JUGOSLAVIA. Internatl. Corn Borer Invest. 2: 111–127.

(8) JONES, D. W.
1929. IMPORTED PARASITES OF THE EUROPEAN CORN BORER IN AMERICA. U. S. Dept. Agr. Tech. Bul. 98, 28 p., illus.

(9) KORNHAUSER, S. I.
1919. THE SEXUAL CHARACTERISTICS OF THE MEMBRACID, THELIA BIMACULATA (FABR.). I. EXTERNAL CHANGES INDUCED BY APHELOPUS THELIAE (GAHAN). Jour. Morph. 32: 531–636, illus.

(10) LEIBY, R. W.
1922. THE POLYEMBRYONIC DEVELOPMENT OF COPIDOSOMA GELECHIAE, WITH NOTES ON ITS BIOLOGY. Jour. Morph. 37: 195–285, illus.

(11) ———
1926. THE ORIGIN OF MIXED BROODS IN POLYEMBRYONIC HYMENOPTERA. Ann. Ent. Soc. Amer. 19: 290–299.

(12) ——— and HILL, C. C.
1923. THE TWINNING AND MONEMBRYONIC DEVELOPMENT OF PLATYGASTER HIEMALIS, A PARASITE OF THE HESSIAN FLY. Jour. Agr. Research 25: 337–349, illus.

(13) ——— and HILL, C. C.
1924. THE POLYEMBRYONIC DEVELOPMENT OF PLATYGASTER VERNALIS. Jour. Agr. Research 28: 829–839, illus.

(14) LUNDIE, A. E.
1924. A BIOLOGICAL STUDY OF APHELINUS MALI HALD., A PARASITE OF THE WOOLLY APPLE APHID, ERIOSOMA LANIGERA HAUSM. N. Y. Cornell Agr. Expt. Sta. Mem. 79, 27 p., illus.

(15) MARCHAL, P.
1904. RECHERCHES SUR LA BIOLOGIE ET LE DÉVELOPPEMENT DES HYMÉNOPTÈRES PARASITES. I. LA POLYEMBRYONIE SPÉCIFIQUE OU GERMINOGONIE. Arch. Zool. Expt. et Gén. (IV) 2: 257–335, illus.

(16) NELSON, J. A.
1924. MORPHOLOGY OF THE HONEYBEE LARVA. Jour. Agr. Research 28: 1167–1213, illus.

(17) PAILLOT, A.
1928. ON THE NATURAL EQUILIBRIUM OF PYRAUSTA NUBILALIS HB. Internat. Corn Borer Invest. Sci. Rpt. 1: 77–106, illus.

(18) PAMPEL, W.
1914. DIE WEIBLICHEN GESCHLECHTSORGANE DER ICHNEUMONIDEN. Ztschr. Wiss. Zool. 108: [290]–357, illus.
(19) PARKER, H. L.
1924. RECHERCHES SUR LES FORMES POST-EMBRYONNAIRES DES CHALCIDIENS. Ann. Soc. Ent. France 93: 261–392, illus.
(20) PATTERSON, J. T.
1915. OBSERVATIONS ON THE DEVELOPMENT OF COPIDOSOMA GELECHIAE. Biol. Bul. 29 (6): 333–375, illus.
(21) ———
1921. SEX RATIOS IN PLATYGASTER. Amer. Nat. 55: 180–183.
(22) SARRA, R.
1915. OSSERVAZIONI BIOLOGICHE SULL'ANARSIA LINEATELLA Z., DANNOSA AL FRUTTO DEL MANDORLO. Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 10: 51–65, illus.
(23) ———
1918. LA VARIEGANA ED I SUOI PARASSITI. Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 12: 175–187.
(24) SILVESTRI, F.
1907. CONTRIBUZIONI ALLA CONOSCENZA BIOLOGICA DEGLI IMENOTTERI PARASSITI. I. BIOLOGIA DEL LITOMASTIX TRUNCATELLUS (DALM.). Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 1: 17–64, illus.
(25) ———
1908. CONTRIBUZIONI ALLA CONOSCENZA BIOLOGICA DEGLI IMENOTTERI PARASSITI. II. SVILUPPO DELL'AGENIASPIS FUSCICOLLIS (DALM.) E NOTE BIOGRAFICHE. Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 3: 29–84, illus.
(26) ———
1910. NOTIZIE PRELIMINARI SULLO SVILUPPO DEL COPIDOSOMA BUYSSONI MAYR. Monitore Zool. Ital. Anno 21 (11–12): 296–298.
(27) ———
1914. PRIME FASI DI SVILUPPO DEL COPIDOSOMA BUYSSONI (MAYR), IMENOTTERO CALCIDIDE. Anat. Anz. 47: 45–56, illus.
(28) ———
1915. STRUTTURA DELL' OVO E PRIME FASI DI SVILUPPO DI ALCUNI IMENOTTERI PARASSITI. Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 10: 66–68, illus.
(28a) ———
1922. LA TIGNOLA NANELLA (RECURVARIA NANELLA HÜBN.) Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 16: 285–299, illus.
(29) THOMPSON, W. R., and PARKER, H. L.
1928. THE EUROPEAN CORN BORER AND ITS CONTROLLING FACTORS IN EUROPE. U. S. Dept. Agr. Tech. Bul. 59, 63 p., illus.
(30) VOUKASSOVITCH, P.
1927. OBSERVATIONS BIOLOGIQUES SUR LE MACROCENTRUS ABDOMINALIS FAB., BRACONIDE PARASITE. Compt. Rend. Soc. Biol. [Paris] 96: 379–381.
(31) ———
1929. CONTRIBUTION À L'ÉTUDE DE MACROCENTRUS ABDOMINALIS F. ET DE SES PARASITES. Ann. Soc. Ent. France 98 (1–2): 163–187, illus.
(32) WEISSENBERG, R.
1909. ZUR BIOLOGIE UND MORPHOLOGIE ENDOPARASITISCH LEBENDER HYMENOPTERENLARVEN (BRACONIDEN UND ICHNEUMONIDEN). Sitzber. Gesell. Naturf. Freunde Berlin 1909: 1–28, illus.

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A REVISION OF THE AMERICAN SPECIES OF EMPOASCA KNOWN TO OCCUR NORTH OF MEXICO

BY

DWIGHT M. DELONG
Collaborator, Bureau of Entomology

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page
Introduction	1
The economic problem and its relation to taxonomy	2
Geographical distribution	5
Historical résumé	6
The genus and its position	7
External structural characters	8
Characters used in classification	9
The vertex	9
The last segment of the female	9
Male structures	9
Male genital pieces	10
Technic and method of study	12
Classification of the species of Empoasca	14
Key to the subgenera of Empoasca	14
The subgenus Kybos Fieber	14
The subgenus Hebata nov	32
The subgenus Empoasca Walsh	36
The subgenus Idona nov	50
List of described species with synonyms	57
Species not included in this revision	58
Literature cited	58

INTRODUCTION

Previous work on the genus Empoasca [2] in the form of monographic studies has been published by both Gillette (*13*)[3] and Hartzell (*17*, *18*). During the last 30 years the pioneer work of Doctor Gillette, in particular, has filled an important place as a guide for workers on the species of this genus. Economic problems, however,

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Since submitting this manuscript for publication (August, 1929) E. P. Van Duzee has published (Pan-Pacific Entomologist 6: 148, April, 1930) the description of *Empoasca denaria* V. D. This is probably the species treated in this bulletin as *E. rubida*.

[2] Order Homoptera, family Cicadellidae.

[3] Italic numbers in parentheses refer to Literature Cited, p. 58.

brought about by species of this genus which have become important, have called for a more fundamental taxonomic basis upon which to build a species concept. The economic worker has not been able to determine definitely whether individuals of this genus found on various cultivated or wild host plants belonged to one or several species.

It is apparent that climatic or atmospheric factors and other similar vague terms have been used to explain differences in injury or crop infestations when a taxonomic problem alone was involved and when a knowledge of the insects would have properly explained these differences. The species could not be differentiated, neither could the problems be solved satisfactorily, with the previous inadequate characters. The urgent need for the differentiation of these insects, some of which are of great economic importance, furnished the chief stimulus that has produced the present study of this genus.

THE ECONOMIC PROBLEM AND ITS RELATION TO TAXONOMY

A full discussion of the economic importance of this group, with its various problems and diverse phases of economic interrelationships, does not belong to the present treatment of the genus. Therefore only a brief statement of this nature with special reference to the previous taxonomic standing of economic species, host-plant relationships, and distribution will be attempted.

The potato leaf hopper, *Empoasca fabae* Harris, has been considered for several years the most important economic species of the genus because of its severe damage to potatoes, beans, clover, alfalfa, rhubarb, eggplant, cotton, aster, dahlia, apple, and many other cultivated and wild host plants. This insect has been variously confused with other species, and in view also of its many variations in color and markings it has been designated in literature under at least eight different names. It has been called *E. flavescens* by many workers since the early work of Gillette placed *flavescens* (referring to this insect) as a common species in North America. But *flavescens* is apparently a purely European species, and present work upon specimens from the British Museum and from various European localities and comparisons with material available for study in the more important collections from Canada and the United States have shown that *flavescens* does not occur in North America. No economic damage in the European countries has been caused by *flavescens* comparable to that which *fabae* has caused in the United States, and it would seem that *flavescens* might be eliminated from present consideration as a possible economic pest in North America.

For many years *fabae* was known as *E. mali*, the specific name being given it by Le Baron (*19*) when he found it on apple in 1853. Walsh (*27*) called its various color forms *consobrina*, *viridescens*, and *malefica*. Forbes (*12*) named it *albopicta* in 1884, and in 1898 Gillette (*13*) called specimens which had been preserved in fluids before mounting by the name of *pallida*.

E. fabae has been considered as well distributed, at least in small numbers, throughout the United States. (Fig. 1, A.) H. H. Sev-

erin, in investigating leaf-hopper problems in California, found that hopperburn did not occur upon potatoes in that area, and that a different type of injury, a white stippling appearance only, was caused by the green leaf hoppers working on potatoes in that and

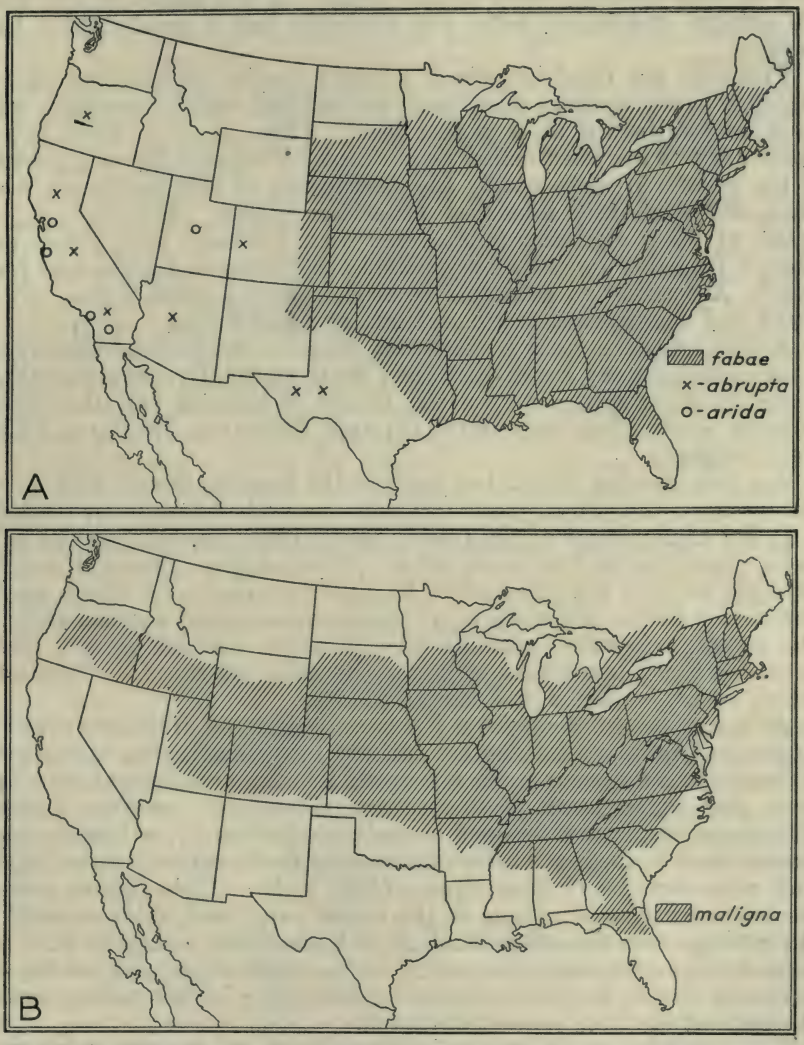

FIGURE 1.—Maps showing the present known distribution of the more common species of Empoasca in the United States: A, Range of *fabae* is indicated by the shading, localities in which *abrupta* has been found are indicated by the crosses, and the distribution of *arida* is shown by circles; B, distribution of *maligna*, the most important species found on Crategus

neighboring States. This leaf hopper has been referred to as *E. flavescens* by Severin (*22*). This difference in injury might have been explained upon the basis of differences in climatic factors, but it is actually due to the fact that, as the present study has revealed, entomologists are dealing with entirely different species of insects

in the case of the California problem and throughout the arid West in general. There are at least three species which have not previously been named or properly designated and which have been confused with *fabae*. In view of its present distribution (Fig. 1, A), one of these species is here named *arida*. It is common in the West on alfalfa and sugar beets and probably has a much wider host range.

Probably the most important western species of economic standing is *abrupta*, another previously undescribed species, which is common in California as a potato pest. (Fig. 1, A.) This is the species which has been called *flavescens* by Professor Severin because it has answered more nearly the description of this European form than the previously described American species. This species, because of its work upon potato, has been confused with *fabae* and should probably be commonly called the "western potato leaf hopper." According to available records it occurs from Texas northward and westward through Arizona and California.

A third western species, *filamenta*, which is widespread and abundant upon potatoes, sugar beets, and beans especially, occurs in abundance in the region between the Rocky Mountains and the Sierra Nevada and extends northward through Wyoming, Montana, Idaho, and Oregon.

Another species which has apparently been confused with *fabae* occurs upon the potato plant in Louisiana and is here named *solana*.

In the eastern part of the United States other common species have been placed under the name *fabae*. The work of Doctor Poos has brought to light the life history of a very common one which passes the winter in the egg stage on *Erigeron annuus* and hatches early in the spring. Another common species which has apparently never been described, but is placed under the name of *fabae*, is *bifurcata*, which occurs on tansy and related plants.

Although the common *fabae* has been designated in literature as the apple leaf hopper, it is not essentially or primarily an apple pest, although it may occur upon the apple in comparatively small numbers, and young apple trees may occasionally be severely injured. The green apple leaf hopper is *maligna* (*unicolor*), a larger, more broad-headed species which apparently feeds entirely upon apple and wild varieties of Crataegus. (Fig. 1, B.) This species spends the winter in the egg stage in the apple twigs and hatches early in the spring. On the other hand, *E. fabae* usually makes its first appearance upon apple in the spring in the adult stage, and adults are normally found in small numbers upon apple in the spring before the eggs of the first generation hatch.

Considerable loss is caused in Florida by *minuenda*, which is a serious pest of avocado, and occurs in large numbers upon these trees. Several other species cause injury to different types of plants, but as many or all of these plants are economically unimportant, the insects are probably viewed in the same light. As a rule, when the food plants are known, the plant or group of related plants is found to be quite well defined for each species. The willows are attacked by *obtusa*, *smaragdula*, *osborni*, *albolinea*, *aureoviridis*, and *clypeata*, and probably others. These species have no important place in the literature because the willow is not an important economic plant.

But in a willow garden, where these plants are raised and used for the making of baskets and furniture, the injury about the oviposition scars causes loss, since the injured shoots can not be bent without breaking.

The species *trifasciata* is common on cottonwood (*Populus deltoides*), and *coccinea* is found on white pine (*Pinus strobus*); whereas the sagebrush (*Artemisia tridentata*) has a considerable population composed of *nigra* and varieties, *nigroscuta*, *typhlocyboides*, and *pulchella*. Species of Alnus support *atrolabes* and *unica*, and *junipera* is found on red cedar (*Juniperus virginiana*) throughout eastern Tennessee.

The importance of careful and thoroughly reliable taxonomic work by economic entomologists can not be easily overemphasized. Many economic aspects and phases of the present economic problem have remained unsolved or unknown for years because of inadequate taxonomic work. Practically none of the economic workers on problems concerned with insects of this genus have been able to determine food plant or geographic distribution because they were unable to differentiate the species on account of identical color characters. As a consequence our literature contains many erroneous statements concerning economic problems relating to Empoasca. It is evident that it is essential to know the correct identity of any species of this genus in order to predict or ascertain its economic status and its capacity for causing economic damage. Personal observations in the field have shown that when a green Empoasca leaf hopper appears upon a wild host plant in early spring, it can not be assumed, as has been the custom in the past, that it is *fabae*, even though it resembles *fabae* in size, appearance, and coloration.

GEOGRAPHICAL DISTRIBUTION

It is quite evident from material examined that the genus Empoasca is widely distributed. It is known to occur rather generally in North America and South America and is apparently abundant in Central America. Several species occur in Europe and Asia, and Naude (*20*) has found the insects in South Africa. The genus is probably more widely distributed than the foregoing data would indicate, especially in many intervening areas.

The exact distribution of any single species over large areas is uncertain at the present time, judging from results obtained during the present study. The economic species have probably seldom been correctly identified in different areas, especially those widely separated, and consequently the data which have been previously presented can not be relied upon. For instance, none of the material collected in North America has proved to be *flavescens*, and the distribution of this species is apparently more limited than was previously supposed. Likewise *fabae* has not been found on the west coast or in the mountain region of the Western States, and it is doubtful if this species is as widely distributed as has been previously stated. The whole question of distribution has been suddenly changed by the finding of more accurate or reliable specific characters, and the consequent finding that many of these leaf hoppers are entirely different from others which were previously thought to belong to the same species.

HISTORICAL RÉSUMÉ

As far as available records show, the first species of the genus as it now stands was described in 1794 by Fabricus (*6*, *p. 46*) under the name of *Cicada flavescens*. In 1806 *C. smaragdula* was described by Fallen (*7*). In 1841 Harris (*16*, *p. 186*) described *fabae* under the generic name Tettigonia. Fitch in 1851 (*11*) described *coccinea* from pine as belonging to the genus Empoa. In 1858 Stål (*23*, *p. 195*) described *pura* as a member of Typhlocyba. This species was later cited as occurring in North America, but it probably does not occur here. The genus under discussion, however, was not described or named until 1864, when it was given the name Empoasca by Walsh (*27*). At this time he designated three species, *viridescens*, *obtusa*, and *consobrina* as belonging to this genus. In the same paper he discussed the genus Empoa and wrote:

> Two species, one on pine and the other on oak, are described by Doctor Fitch, in his catalogue of New York Homoptera, and referred to this genus. As he says nothing of the neuration of the wings, they may possibly belong to Empoasca. *Empoa rosæ* and *E. fabæ* Harris, are in the same predicament.

The species on pine was undoubtedly *coccinea*. Both *coccinea* and *fabae* have been placed in Empoasca, and the other species referred to in the above citation by Walsh have been placed in Typhlocyba. Walsh also described the genus Chloroneura at the same time and placed *malefica* and *maligna* in this genus, but made *abnormis*, which is now placed in Dikraneura, the type.

Two years later, in 1866, Fieber (*9*, *p. 508*) described the genera Chloria and Kybos. The former of these was preempted, and in 1872 (*10*) he proposed the name Chlorita for Chloria, and in 1875 Douglas (*5*, *p. 26*) gave the name Cybus as an emendation of Kybos.

Uhler (*24*, *p. 474*) in 1877 described *aureoviridis* under the genus Typhlocyba. Woodworth (*28*, *p. 212*) in 1889 attempted to group in a general way the American species previously described. He recognized the genus Kybos as distinct and made Chlorita a synonym of Kybos.

In 1890 Provancher (*21*, *p. 340*) described *unica* as a member of Typhlocyba, and Goding (*15*) described *birdii* as an Empoasca.

In 1895 Gillette and Baker (*14*, *pp. 107–110*) described five species and one variety under the names of *clypeata*, *aspersa*, *nigra*, *pulchella*, *nigroscuta*, and the variety *typhlocyboides* as belonging to Empoasca.

When Gillette (*13*) made the pioneer study of the species as a genus in 1898 (*13*), he placed the genera Chloroneura, Kybos, and Chlorita as synonyms of Empoasca since the characters used for separating these groups were too variable and could not be defined as generic characters. During this study he treated 14 European and American species which had previously been described, and named 16 others as new. This publication by Gillette has formed a working basis for the identification of these species of Empoasca for the last 30 years and has been a valuable contribution to our knowledge of the group in spite of the fact that entomologists have not been able to distinguish correctly the members of the *fabae* group. Gillette placed many names in synonymy and stated in his

introduction to the genus that " a further study will probably reduce others." The present study has proved this to be the case, and such reduction will probably always be necessary when these problems are reworked by future taxonomists who have better series of specimens and have found more constant characters for separation.

In 1914 Van Duzee (*25, p. 56*) described one species, *alboscripta.* With this exception no additions were made to this genus until 1923, when Doctor Hartzell, following his previous economic work, completed a paper on the genus Empoasca (*18*). In this paper he recognized all of the species previously described and added five which had not been named. Hartzell followed Gillette almost precisely and failed to distinguish the economic from allied species although he had previously studied the same material which was used for the present revision. In view of the fact that he did not distinguish between the eastern and western economic species and that several apparent synonyms of economic species remained unplaced, and since problems in biology, host plants, relationships, occurrence, and distribution of certain species remained unsolved, the present treatment was undertaken. An attempt is here made to rely on constant structural characters for identification purposes in so far as material is available in sufficient quantity to make possible the determination or ascertainment of these characters.

THE GENUS AND ITS POSITION

The genus Empoasca is closely allied to several other genera of small delicate leaf hoppers belonging to the subfamily Eupteryginae (Typhlocybini of Van Duzee). These are members of the order Homoptera and family Cicadellidae. This subfamily was previously distinguished from the other leaf hopper subfamilies by the absence of ocelli, reduction of venation at the base of the first pair of wings, and a few other minor characters. But a large number of the species of Empoasca, as well as members of other of these genera, have conspicuous ocelli. In many species the veins of the first pair of wings are conspicuous to the base, especially when a satisfactory method of study and technique is devised. But as a rule the weak venation at the base of the first pair of wings, the reduction or absence of claval veins, and the absence or reduction of anteapical cells is a good basis for separation.

The genus Empoasca can most easily be distinguished from its allied genera by the absence of an appendix in the first pair of wings and the possession of one apical cell in the posterior wing which is closed by a submarginal vein. No anteapical cells are present in the wings of these species.

Most of the species of Empoasca are of some shade of green with faint or variable markings. Bright pigmentation of red or other colors is occasionally found.

Although this group has been treated as a single genus, there are distinct and well-defined subgroups which the writer has chosen to designate as subgenera. The type of head (fig. 2) is probably the best character for the separation of the subgenera since it is easily recognized and quite constant.

EXTERNAL STRUCTURAL CHARACTERS

In all fairness to the previous workers it should be said that, with the exception of a few species, good external structural characters are lacking in this group, and as a consequence it has been necessary to resort to the structures in the male genital chamber which are usually concealed in the normal specimen. These are often referred to as internal genitalia. Yet if it must be decided whether a given form belongs to a species of economic importance and there is no other distinctive structural character, resort must be had to such differences for the more basic work. The external genital charac-

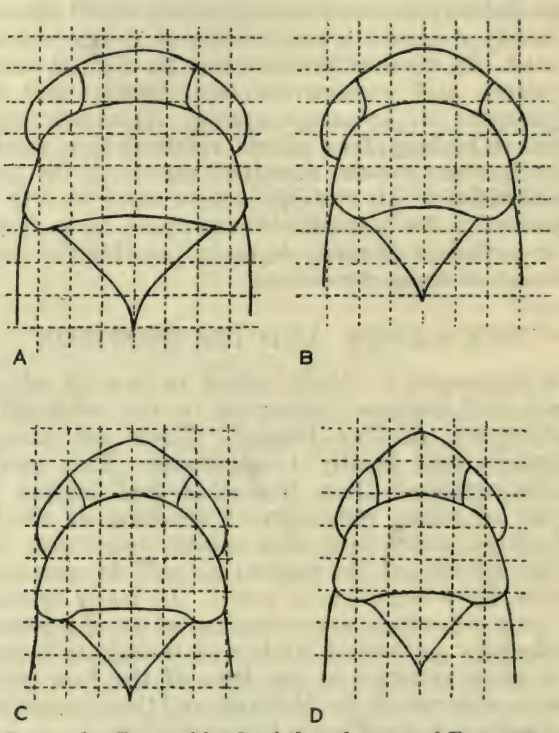

FIGURE 2.—Types of heads of the subgenera of Empoasca: A, Head of *atrolabes*, an example of the subgenus Kybos Fieber; B, *aspersa*, example of the subgenus Hebata nov.; C, *abrupta*, example of subgenus Empoasca Walsh; D, *radiata*, example of subgenus Idona nov.

ters are usually constant, but are so similar for most of the species of the genus that they can not be used as characters for specific designation.

Good external characters have been used in previous work on the genus for the separation of a limited number of species, but color characters or markings have been the basis for separation of the majority of the species of Empoasca. Most of the species of the genus, however, are rather uniformly green in color with but faint or variable markings and do not present the striking contrast in color which is seen between species of most of the allied genera. Color characters are somewhat variable at best, but it is almost im-

possible to use color in the case of the number or size of small spots or blotches on the vertex or pronotum of these rather uniformly colored species. For in these species there is a wide variation in such markings, and it has happened that specimens belonging to the same species and occurring upon the same food plant have been separated by this color character and placed under different specific names.

On the other hand, several similarly marked species have been placed under the same name. It is true that the similar color pattern is frequently a good recognition mark or indicator of the species concerned, but there should be a more basic character used for the designation of a type as a species, especially where wide geographic localities are represented or food-plant differences or greatly differing types of injury are apparent. Banding or striping is usually a rather constant character, but intensity of color and width of bands or stripes will vary, and these color markings may frequently be entirely wanting.

In the previous division of the species of the genus, wing venation was used as a chief character. Although certain groups can be separated in this way, the characters or types of characters seem to be too variable for specific separation.

CHARACTERS USED IN CLASSIFICATION

THE VERTEX

The shape and type of the vertex is used as a basis for dividing the genus into subgenera. The broadly curved head which is only slightly produced before the anterior margins of the eyes is a good character for the subgenus Kybos and separates those species quite easily from the group with the strongly curved or angled vertex which is rather strongly produced before the anterior margins of the eyes. Varying degrees of this curvature or length of vertex may occur, and this difference is used in grouping the species. The comparative length of vertex to basal width between the eyes is used in most species and is a rather constant character and easily recognized. (Fig. 2.)

THE LAST SEGMENT OF THE FEMALE

The ventral surface of the last segment (sternum or segment 7) of the female presents a good character for the separation of species in a few cases. Species like *pergandei*, *maligna*, *atrolabes*, *acodens*, *pectinata*, *trilobata* (fig. 3), and probably a few others can be distinguished by the notching or by other characters on the posterior margin of the last ventral segment, but in most of the species this character is of no value as the female segment is usually roundedly produced and entire.

MALE STRUCTURES

The external male structures are of practically no value for specific separation. For group characters the plates are frequently excellent and can be used to separate a group of closely related species from another similar group or groups. This is illustrated

by the long slender plates of the *maligna* group, as contrasted with the broad, heavily spined, apically upturned, and compressed plates of the *obtusa* group. So far as has been found, the male genital pieces located in the genital chamber and usually called the internal male genitalia are constant and excellent characters. These structures are composed of the oedagus, a central structure; a pair of ventral styles lying just dorsad of the plates; the style-oedagus connectives uniting these structures; and a pair of processes termed the lateral pygofer processes, which arise near the base on the dorsal sides of the pygofers. These last structures have not previously

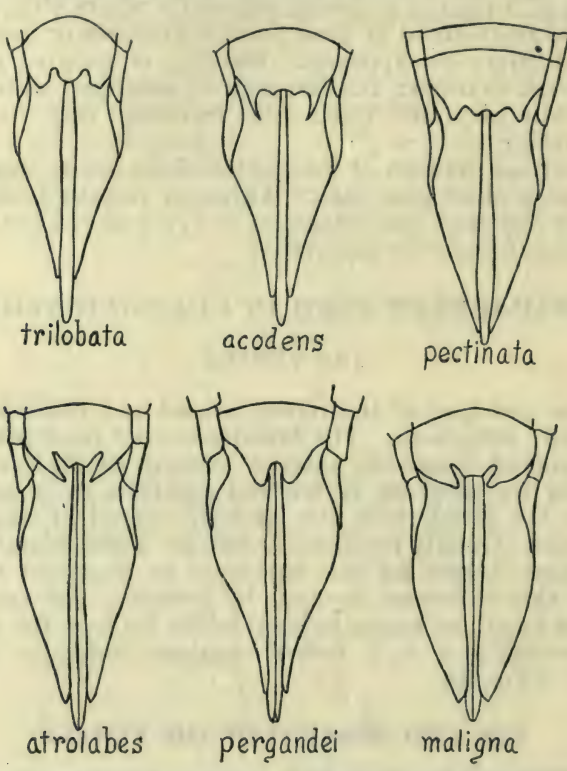

FIGURE 3.—Last segment of the female of six representative species of Empoasca

been seen in other genera, and no reference can be found in literature regarding them. Previous workers who have studied the internal genital pieces of species of Empoasca have apparently attempted to find only those pieces represented in the genital chamber of species of other genera. As a consequence none have figured or described the lateral processes of the pygofers.

MALE GENITAL PIECES

Figure 4 is a drawing of the male genital pieces of *maligna* in which the various structures used for separating the species are indicated both by name and by the type of line used in delineating

them. These same lines, a succession of dashes for the styles, a dash and dot for the oedagus, and a dash and three dots for the lateral processes of the pygofers, have been used in all the subsequent illustrations to distinguish these parts.

THE OEDAGUS

The oedagus is very similar in most of the species of the genus and is usually extended dorsally and enlarged at the apex to form a pair of proximate broad, flat plates. The general outline of the oedagus may vary slightly, but no good specific characters are exhibited except in species like *atrolabes*, where a long, ventral, apically extended spur arises near the middle on the posterior side; and in species like *coccinea* in which the ventral end of the oedagus is curved, and a pair of long structures, longer than the oedagus, extend caudally and dorsally.

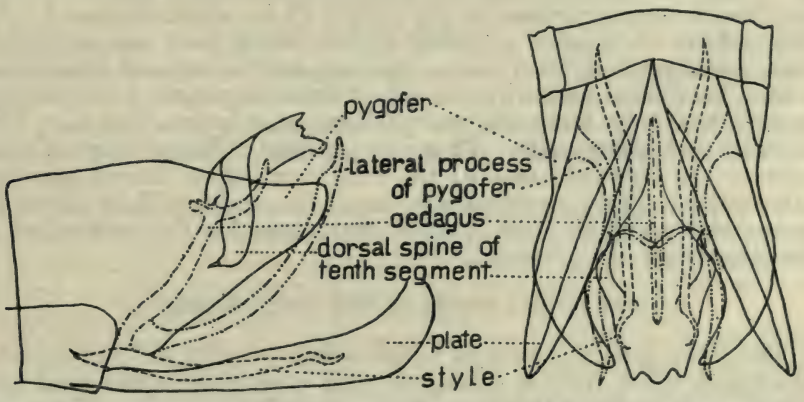

FIGURE 4.—Male genital pieces of *maligna*, with the various structures indicated by name and by the type of line used. In this and in the following drawings the styles are represented by a line of dashes, the oedagus by a dash and a dot, and the lateral processes of the pygofers by a dash and three dots

THE STYLES

The styles, which are just dorsad of the plates, are quite different throughout the species of the genus, and specific characters could undoubtedly be secured by the use of these structures. They are not as distinctive, however, in most species as the pair of structures which lie just above them and arise from the lateral walls of the pygofers.

THE LATERAL PROCESSES OF THE PYGOFERS

The lateral processes arising from the pygofers are paired and are found to occur as prominent structures throughout the genus. In both lateral and ventral view they present structures, especially terminal processes, which are constant and are good characters for specific separation.

In certain groups of closely related species where slight differences in coloration have been used previously for specific characters in an attempt to separate them, these processes will be found to be excellent distinguishing characters. The *fabae* group has been confused by

this attempted separation on a color basis, and it is safe to say that no worker has ever been sure whether he had *fabae* or some closely related species. A study of the shape of these processes in *fabae*, as detailed in the ventral view in Figure 10, will show that they are roundedly broadened on the inner margin and then concavely tapered to the acute apex. It will be noted also that *flavescens* (fig. 10), the European representative of this group, a drawing of which is given for comparison with the American species, has the lateral processes enlarged and broadened near the apex, which is rounded from the outer margin to form an apex on the inner margin. In like manner the only structures by which *arida* (fig. 10), one of the common western species, may be distinguished from either of the former is by the curved, hooklike structure at the apex of these lateral processes. Superficially *abrupta* (fig. 10), a very common potato-infesting species in the West, resembles exactly these former species, and the abrupt narrowing, together with the produced finger extensions of these lateral processes, is the only way in which it may be distinguished. A number of other species which have not previously been distinguished from *fabae*, and can not be without these characters, have been found by the aid of these structures to be distinct species not only from the morphologic standpoint, but also biologically and ecologically. They also produce different types of plant injury. In *bifurcata* (fig. 9) the long vermiculate lateral processes are unique. These processes are variously modified throughout the genus and serve as good specific characters for the separation of practically all of the species.

THE DORSAL SPINES OF THE TENTH SEGMENT

The large spines, a pair of which occur dorsally on every species examined, arise from a chitinous ring surrounding the anal tube which is apparently the remnant of the tenth segment. They may extend inwardly into the genital chamber, or ventrally and anteriorly, or posteriorly. They are of various size, shape, and curvature and furnish excellent characters in the different species, especially when used in combination with the lateral processes of the pygofers. In *bifurcata* this spine structure is long and bifurcate with two terminal processes, and furnishes an unique character for determination.

TECHNIC AND METHOD OF STUDY

Similar methods of preparation and study of the chitinous structures of the male genital chamber have been used by different workers, and some of these methods have been described in previous papers by the writer and others. In the present study, at least the last four segments of the abdomen were removed by a sharp pointed scalpel or a very fine needle made by using a minute pin in a small wooden handle. If the insect is mounted on a point, this portion can usually be removed without further mutilation of the specimen or loosening it from the pin, if proper care and skill are used. By holding the pin so as to place the insect upside down with the point

where the abdomen is to be severed resting on the narrow edge of a small watch glass or similar surface, the needle can be inserted on the ventral side and the abdomen will usually part very easily. The removed portion is then placed in potassium-hydroxide solution. A 10 per cent solution will suffice, but a much stronger solution will usually expedite the process. With frail-bodied insects of this type it is better to leave them in this solution for a few hours without heating, for when heated the structures are usually distorted, but when allowed to soak gradually they remain normal.

After the softer parts of the body have been destroyed by the caustic-potash solution, the specimen is placed in an aqueous solution of glycerin with about 5 per cent of potassium hydroxide. It soon clears and should then be transferred to pure glycerin.

It was found that the most satisfactory way to handle and study these prepared specimens was to place them in small glass hydrogen-ion test cups. The strength of transmitted and reflected light can be adjusted for this type of container. The cups are very small and can be labeled on the side, easily handled, and stored temporarily in tin salve boxes for protecting and preserving the specimens. The glycerin makes an ideal medium for use in this study, since it is transparent, viscid, and nonvolatile, and specimens can be left in this material for several weeks or months without change in form or appearance.

If it is desirable to make drawings of these structures after comparative study, very minute pieces of broken glass can be used to hold them rather firmly at any angle as long as desired while submerged in glycerin in these cups. The specimens can afterwards be easily referred to for checking the details of the drawings.

Several workers in this field have been accustomed to mount these abdominal structures on slides and allow the cover glass to press upon them, thus changing the normal position and frequently the appearance of these structures before illustrations are made from them. Others have dissected out certain of these pieces and mounted them before drawing. It is the opinion of the writer that neither of these methods is so satisfactory as to study and draw these structures in natural position in the inflated abdomen as they are found normally. The student or worker can always duplicate this natural position for study, whereas it is doubtful if both or either of the former arrangements will permit of exact duplication of position with other specimens. This is important, as the relative position of the chitinous structures within the abdomen, their curvature, comparative length, and normal extension beyond the genital chamber are all important factors which are lost for identification if either of the former methods of preparation is used.

In order to make a drawing from the side the abdomen is rotated until one structure, in the case of paired structures, is superimposed upon the other.

If accurate measurements are made through the use of an ocular micrometer ruled in 0.05-millimeter squares and the outlines are then drawn on coordinate paper, little chance for play of the imagination will be left.

CLASSIFICATION OF THE SPECIES OF EMPOASCA

KEY TO THE SUBGENERA OF EMPOASCA

A. Vertex broadly rounded, only slightly produced before anterior margins of the eyes and almost parallel margined; or if bluntly angularly produced, the vertex about twice as wide between eyes as median length.
B. Large, at least 3 to 5 mm. in length, usually with broad, rounded vertex which is not greatly produced_____Subgenus Kybos, p. 14
BB. Smaller, not over 3 mm. in length (except *coccinea*), vertex usually more produced and rounded or broadly bluntly angled _____Subgenus Hebata, p. 32
AA. Vertex usually distinctly roundedly or angularly produced at middle, never parallel margined, and width between eyes usually not greatly exceeding one-half more than length.
C. Vertex angled and well produced but usually not more than one-half longer at middle than next the eyes (sometimes longer in *arida*)_____Subgenus Empoasca, p. 36
CC. Vertex strongly produced, usually distinctly angled, almost twice as long at middle as next the eyes_Subgenus Idona, p. 50

THE SUBGENUS KYBOS FIEBER

Vertex broad, almost parallel margined, scarcely produced before anterior margins of eyes. Largest species of group wedge-shaped in appearance.
Type of subgenus, *smaragdula* Fallen.

KEY TO GROUPS

A. Male plates long and narrow with almost parallel margins to near base, at least five times as long as basal width. Female segment usually notched, incised or lobed at apex_____*maligna* group, p. 14
AA. Male plates broader at base and tapered, usually heavily clothed with spines. Plates not more than four times as long as broad. Female segment usually entire on posterior margin_____*obtusa* group, p. 19

KEY TO THE SPECIES OF THE MALIGNA GROUP

A. Green without definite color markings except black spot before inner apical cell of elytron.
B. Female segment notched or with projecting teeth.
C. Female segment with a median U-shaped notch, styles of male tapered to rather acute tips_____*pergandei*, p. 15
CC. Female segment with teeth or median lobe, no U-shaped median notch; males unknown.
D. Female segment with teeth on outer angles.
E. Female segment with a long, slightly curved, sharp pointed tooth one-third the length of segment projecting from each outer angle, central portion with a pair of short teeth_____*aeodens*, p. 16
EE. Female segment with teeth shorter and more blunt on outer angles, median third forming a broad tooth which is notched at middle___*pectinata*, p. 16
DD. Female segment without teeth, divided by two rounding incisions into three rounded lobes_____*trilobata*, p. 17
BB. Female segment with an oblique notch either side of median sunken tooth, styles of male with the apical portion strongly curved. (Figs. 3, 5)_____*maligna*, p. 17
AA. Brownish green to red, claval vein blue to bright red.
F. Dark green to brown, claval suture bluish, female segment with an oblique notch either side of sunken median tooth; male lateral processes of the pygofers long, tapering, and slightly sinuate near apex, oedagus with ventral caudal process_____*atrolabes*, p. 18
FF. Brighter in color, almost red, female segment rounded, without notch; male lateral processes of the pygofers expanded before tip and spearlike_____*unica*, p. 19

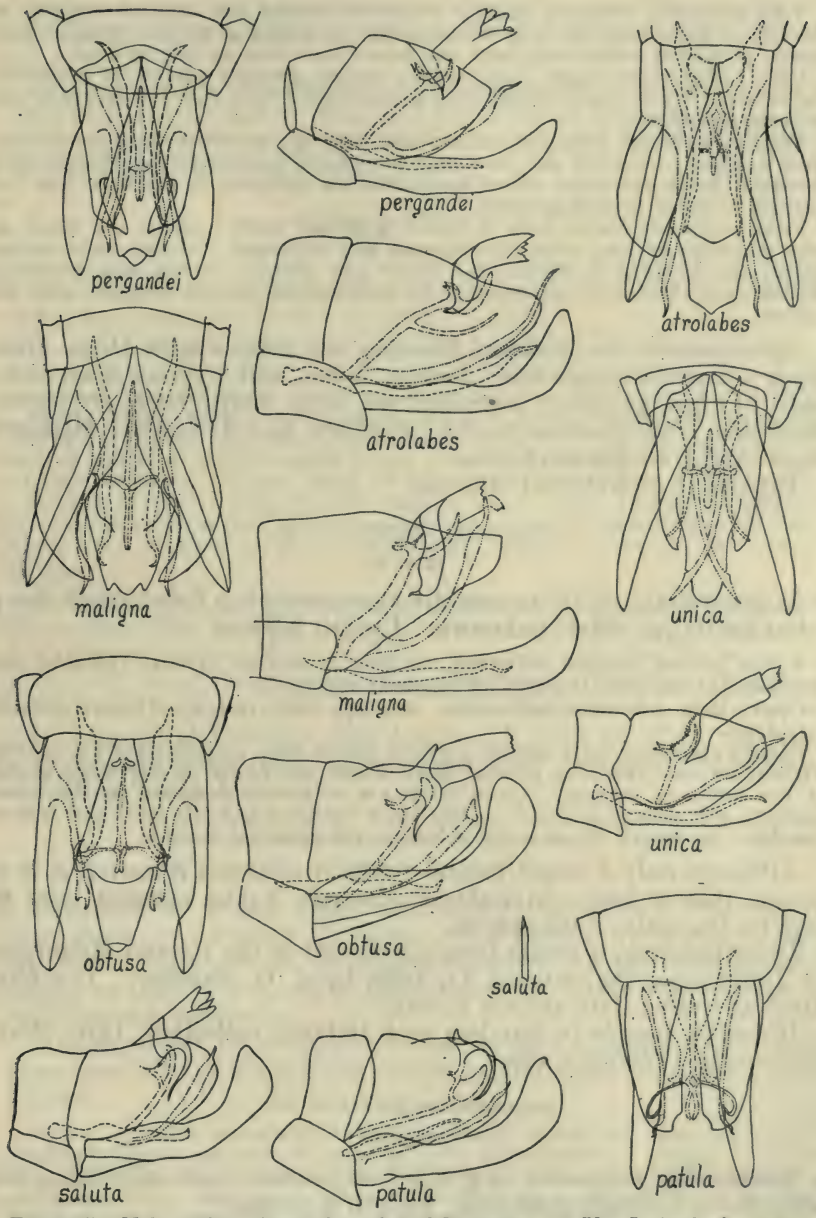

FIGURE 5.—Male genital pieces of species of Empoasca. ×50. Instead of a complete drawing of the ventral aspect of the genitalia of *saluta*, only the apical portion of the lateral process of the pygofer is shown

SPECIES OF THE MALIGNA GROUP

EMPOASCA PERGANDEI GILLETTE

(Figs. 3 and 5)

Described by Gillette as an Empoasca in 1898 (*13*).

In form, size, and color resembling *maligna*, but with a large black spot just before cross vein of inner apical cell and with genitalia distinct. Length 3.75 mm.

Vertex broadly rounded, slightly produced beyond the anterior margins of the eyes, almost twice as wide between eyes as length at middle, parallel margined; pronotum wider than head and more than twice as long as head.

Color: Pale green tinged with yellow; vertex, anterior portion of pronotum, and scutellum yellowish; elytra with a large black spot just before cross vein of inner apical cell.

Female genitalia: Last ventral segment with the posterior margin convexly, then concavely rounded and produced to central half which is divided by a U-shaped notch extending about one-fourth the distance to the base into two broadly rounded projecting lobes.

Male genitalia: Valve with a broad V-shaped notch; plates six times as long as width at base with tips tapered and upturned. Of the male genital pieces, the oedagus is simple, the styles are slightly curved and gradually tapered, and the lateral processes of the pygofers are curved inwardly near the apices.

Specimens in the National Museum are from Forest Hills, Mass. (type), Arnold Arboretum, Boston, Mass., and a series from Colorado. Other specimens examined are from North East, Dromgold, Rockville, and Hartstown, Pa. (Sanders and DeLong), Medford, Mass., and New Haven, Conn.

Type in U. S. National Museum.

EMPOASCA ACODENS N. SP.

(Fig. 3)

In general appearance resembling *pergandei* but female with sharp lobed genitalia. Male unknown. Length 3.5 mm.

Vertex almost parallel margined, as long at middle as next the eyes and twice as wide between the eyes as length at middle.

Color: Pale greenish subhyaline washed with yellow, without definite markings.

Female genitalia: Last ventral segment rather long, posterior margin slightly sinuate between two long pointed teeth which are found on the outer angles of the posterior margin. These teeth are concavely rounded on the inner margins and almost straight on the outer margins and are produced almost one-third the length of the segment beyond the posterior margin.

Although only a single female exists in collected material, it is so unique that it seems advisable to describe it and attempt later to capture the male of the species.

Described from a single female collected in the Pocano Mountains at Tobyhanna, Pa., August 14, 1920, by J. G. Sanders. The food plant and other data are not known.

Holotype female in Sanders and DeLong collection, Ohio State University, Columbus, Ohio.

EMPOASCA PECTINATA N. SP.

(Fig. 3)

Resembling *pergandei* in general appearance and coloration, but with distinct female genitalia. Length 3.75 mm.

Vertex parallel margined, twice as wide as length at middle and as long at middle as next the eye; pronotum with prominent humeral angles.

Color: Pale green, vertex and pronotum washed with yellow; elytra with a large black spot on either wing just before inner apical cross vein; apices of elytra hyaline and without coloration.

Female genitalia: Last ventral segment with the posterior margin composed of three or four distinct teeth; if three, the central tooth is about twice as broad as the two outer teeth and with a deep notch on each side; or the central tooth may be divided and present a row of four pointed teeth almost equal in size comprising the entire posterior margin.

This may prove to be only a varietal form, but the smaller size and distinct genitalia of the female seem to mark it as a distinct form.

Described from two female specimens in the collection of E. D. Ball, collected by him at Soldier, Utah, August 13, 1906.

Holotype female and paratype female in the E. D. Ball collection, University of Arizona, Tucson, Ariz.

EMPOASCA TRILOBATA N. SP.

(Fig. 3)

With head more produced than in *pergandei* and with female genitalia distinctly lobed. Length 3.5 mm.

Vertex roundedly produced, a little longer on middle than next the eye, and practically twice as wide between eyes as length at middle; pronotum with prominent humeral angles which are produced and wider than the vertex.

Color: Bright green, vertex, pronotum, and scutellum washed with yellow. Vertex with three pale areas; pronotum with three irregular pale areas just back of posterior margin; elytra bright green to apical cross veins, then hyaline without coloration; a large black spot just before inner apical cross vein.

Female genitalia: Last ventral segment about twice as long as preceding, posterior margin rather deeply roundedly notched on either side of central third, thus forming three rather broadly rounded lobes on the posterior margin.

Described from three female specimens. The holotype is from Snow Shoe, Pa., and was collected August 22, 1918, by J. G. Sanders. An allotype is from Woburn, Mass., and was collected September 26, 1919. A third female specimen, although differing slightly, is thought to belong to this species. It is designated a paratype and was collected at Penfield, Pa., August 24, 1918, by J. G. Sanders.

Holotype female and paratype females all in Sanders and DeLong collection, Columbus, Ohio.

EMPOASCA MALIGNA (WALSH)

(Figs. 3, 4, and 5)

Described by Walsh under Chloroneura in 1864 (*27*) as the common green leaf hopper on apple. The female was redescribed by Gillette in 1898 (*13*) as *Empoasca unicolor*. In the same paper the males, as they now stand in the museum as types, were redescribed as *Empoasca denticula*.

Distinguished from the other species of the genus by the bright green color, blunt head, and external genitalia of both sexes. Length 3.5 mm.

Vertex parallel margined, broadly rounded anteriorly and only slightly produced beyond anterior margins of eyes, width between eyes a little more than twice length at middle; pronotum with prominent lateral angles and appearing wider than head, more than twice as long as head; elytra long, rolled at apex, giving the insect a wedge-shaped appearance.

Color: Bright green, markings varying; usually with a median longitudinal stripe on vertex extending on to anterior portion of pronotum, a spot either side on vertex, and posterior margin of pronotum pale; scutellum usually orange-yellow with median pale stripe; face, vertex, and pronotum frequently tinted with orange; elytra bright green, apical fourth smoky.

Female genitalia: Last ventral segment with posterior margin roundedly produced to a central rather broad, blunt, sunken tooth formed by an obliquely directed notch on either side.

Male genitalia: Valve with a broad deep V-shaped notch extending more than halfway to base; plates long and narrow, more than five times as long as width at base; male genital pieces similar to those of *pergandei*; lateral processes of the pygofer long and slightly curved at tip; styles long and narrow, almost straight, and with inwardly curved apices (ventral view).

The type of this species was destroyed in the Chicago fire, and since this species is generally accepted as the one which Walsh had in hand, and in view of the use of this name in literature at present, a neotype is erected at this time for reference for future work and has been deposited in the author's collection. It is labeled "Delaware, Ohio, July 20, 1926 from apple."

Specimens in the National Museum are from Salineville, Ohio (types of *unicolor*), Colorado (male types of *denticula*), and other specimens from Chester, Pa., on apple, Arkansas (on apple), Maryland, and Idaho. Other specimens examined are from North East, Proctor, Charteroak, Kane, Presque Isle, and Snow Shoe, Pa. (Sanders and DeLong) and from Brookings, S. Dak.

Specimens in the collection of Doctor Ball are from Hood River, Oreg. (Childs), Trout Lake and Madison, Wis., Rist Canon, Colo., and Soldier, Utah.

This insect is the true apple Empoasca and is abundant and destructive on cultivated and wild Crataegus. It overwinters as an egg in the apple twigs and hatches early in the spring. This is one of the most important economic species of the genus.

Neotype in the author's collection.

EMPOASCA ATROLABES GILLETTE

(Figs. 2, 3, and 5)

This species was described by C. P. Gillette as an Empoasca in 1898 (*13*).

Differs from closely related species by its dark-green color with pale-brownish markings and the large black spot near the apex of the wing. Genital characters similar to *maligna*. Length 3.5 mm.

Vertex scarcely produced beyond anterior margins of eyes, broadly rounded, a little more than half as long on middle as width between eyes; pronotum with prominently produced humeral angles, slightly wider than head and more than twice as long.

Color: Dark or dull green, vertex with pale mottling, anterior half of pronotum and scutellum yellowish brown; elytra with claval vein bluish green, a large black spot before the cross nervure of the inner apical cell, apical fourth of elytra smoky.

Female genitalia: Last ventral segment angularly produced to center of posterior margin where a broad sunken tooth sometimes notched at middle is formed by an oblique notch either side. The posterior margin ends in a sharp point on either side of this central excavation.

Male genitalia: Valve with a deep V-shaped notch as in *maligna;* plates long and narrow, about six times as long as width at base. Of the male genital pieces, the oedagus differs from that of any of the closely related species by having a long ventral caudal spur which projects from the body of the oedagus about two-thirds the way from the base, lateral processes of the pygofers very long and slightly waved at the apex, the styles much shorter and tapered at apex.

This insect is northern in distribution. The cotypes in the National Museum are from the Michigan Agricultural College, from New Hampshire, Colorado, and Massachusetts. Other specimens examined are from North East, Hartstown, and Bear Meadow, Pa.

Specimens in the E. D. Ball collections are from Ames, Iowa, Rist Canon, Colo., Franconia, N. H., and Oceola, Ladysmith, and Rhinelander, Wis.

This species is found on alder (Alnus) and is not considered of economic importance.

Type in United States National Museum.

EMPOASCA UNICA (PROVANCHER)

(Fig. 5)

Described by Provancher as a Typhlocyba in 1890 (*21, p. 340*) and redescribed by Gillette as *Empoasca splendida* in 1898 (*13*).

Resembling *atrolabes* in form and appearance, but more brightly colored and marked with brownish red and with female segment entire. Length 3.5 mm.

Vertex more angularly produced beyond the anterior margins of the eyes than in *atrolabes*, only a little wider between eyes than length at middle; pronotum as wide as head and about one-half longer.

Color: Vertex bluish green, anterior third yellowish; anterior two-thirds of pronotum brownish red, posterior margin banded with bluish green; scutellum pale brownish; elytra brownish red, a stripe along claval vein and another along costal margin bluish green, apical fourth smoky; face and beneath pale yellowish green.

Female genitalia: Last ventral segment more than twice the length of the preceding, posterior margin roundedly produced.

Male genitalia: Valve angularly notched about half way to base; plates long and very narrow, about six times as long as basal width. Of the male genital pieces, in ventral view the styles are tapered apically and somewhat divergent, the oedagus appears to be short, the lateral processes of the pygofers are long, cross near their apices, and are angularly broadened on the inner margin like a spear.

This species is southern in distribution. Specimens in the National Museum collection are from Alabama, Maryland, and Pennsylvania, all in the C. F. Baker collection. Other material examined is from Battle Point, Va. (Sanders), Hartstown, Pa., and throughout Tennessee (author's collection).

This species is abundant on certain species of alder (Alnus) but is not considered of economic importance.

KEY TO THE SPECIES OF THE OBTUSA GROUP

A. Green or yellowish without definite stripes, bands, or dark markings.
  B. Less than 5 mm. in length.
    C. Male lateral processes of the pygofers enlarged near tip, in ventral view showing a conspicuous projecting fingerlike process on inner margin. (Fig. 5.)----------*obtusa*, p. 20
    CC. Lateral processes of male without fingerlike processes on inner margin in ventral view.
      D. Length 4.5 mm.
        E. Lateral pygofer processes of male in ventral view narrowed before apex, then enlarged. In lateral view with a ventral fingerlike process----------*incida*, p. 21
        EE. In ventral and lateral view male lateral processes tapered to apex and sinuate----------*patula* var. *magna*, p. 23
      DD. Length 4 mm. or less.
        F. Claval vein of elytra broadly white, male unknown ----------*albolinea*, p. 23
        FF. Claval vein same color as elytra, not white.
          G. Male lateral processes of pygofers tapered and sinuate at apex----------*patula*, p. 22

GG. Male lateral processes of pygofers abruptly narrowed near apex to form dorsal fingerlike process (in lateral view) ---------- *saluta*, p. 24

BB. Length 5 mm. or more, lateral processes of the pygofers stout, in lateral view enlarged and tapered near tip ---------- *aureoviridis*, p. 24

AA. Color uniformly brown, black, or banded or striped with dark markings.

H. With definite bands, stripes, or color marking.

I. Size 4 mm. or less.

J. A rather conspicuous dark stripe along inner margins of elytra extending from base of pronotum ---------- *smaragdula*, p. 25

JJ. Elytra not striped but sometimes banded.

K. Green with three conspicuous transverse bands one on the pronotum, one across the middle, and another across the apices of the elytra ---------- *trifasciata*, p. 26

KK. Either not green or without bands.

L. Green with pronotum and scutellum frequently dark brown to black ---------- *digita*, p. 26

LL. White to gray, a brownish band across pronotum and two across elytra, one at apex, and one on middle of clavus ---------- *copula*, p. 27

II. Size larger, 5 mm.

M. A transverse band across apex of elytra black, and a broad longitudinal stripe across vertex, pronotum, and scutellum and on to elytra black ---------- *livingstoni*, p. 27

MM. A large black stripe extending along inner margins of elytra from posterior portion of pronotum to apex of elytra ---------- *aureoviridis* var. *vittata*, p. 25

HH. Rather uniformly dark in color (brownish or black) without bands or stripes.

N. Length 4 mm. or more; western in distribution.

O. Male lateral processes of pygofers long, straight, tapered to acutely pointed tips ---------- *clypeata*, p. 28

OO. Tips of male lateral processes of pygofers not straight.

P. In lateral view with tips of male processes strongly sinuate. Spines of anal chitinous ring more elongate and narrowed than in *clypeata*. (Fig. 7) ---------- var. *annella*, p. 28

PP. Tips of male lateral processes provided with shallow hooks bent laterally and anteriorly. (Fig. 8) ---------- *adunca*, p. 31

NN. Smaller, 3.5 mm., brown; eastern in distribution. Male lateral pygofer processes inflated before apex and with a ventral finger process (lateral view, fig. 7) ---------- *osborni*, p. 31

SPECIES OF THE OBTUSA GROUP

EMPOASCA OBTUSA WALSH

(Fig. 5)

Described by Walsh in 1864 (*27*) as an Empoasca. The female, which has a slight incision in the last ventral segment, was apparently redescribed as *Empoasca incisa* by Gillette in 1898 (*13*).

This is the common green, broad-headed species without definite markings that occurs on willow and poplar. Length 4–4.5 mm.

Vertex produced on the middle half beyond the anterior margin of the eyes, slightly longer at middle than next eye, more than twice as wide between eyes as length at middle; pronotum almost two and one-half times as long as vertex.

Color: Pale green, without definite markings; vertex frequently tinged with yellow; pronotum and scutellum usually with central pale stripe and other irregular light markings; elytra greenish subhyaline, abdomen visible from above.

Female genitalia: Last ventral segment long, produced to blunt rounded apex.

Male genitalia: Valve broad, broadly angularly rounded, almost twice as wide as long; plates more than three times as long as basal width, tapered to curled narrow tips, heavily clothed with long pale spines. Of the male genital pieces, in ventral view the lateral processes of the pygofers are broadened apically and have prominent finger-like projections on the inner margins. These structures are used to distinguish the species of this group. The styles are constricted apically, and the apices are turned outward.

The type was destroyed in the Chicago fire, but in view of the fact that the species is quite well defined in the minds of workers on the Homoptera a neotype is erected at this time and deposited in the author's collection. It is labeled "Mitiwanga Ohio 8–15–27 from willow."

This is apparently a very common species on willow and poplar. Specimens in the National Museum collection are from Colorado (C. F. Baker collection), Ohio, Pennsylvania, Algonquin, Ill., Alabama, and Washington, D. C. Other specimens examined are from Williamsport, North East, Hartstown, and Presque Isle, Pa. (Sanders and DeLong.)

EMPOASCA INCIDA N. SP.

A yellowish species with vertex broad and parallel margined, but somewhat produced. Length 4.5 mm.

Vertex broadly, angularly produced almost one-half its length before the eyes, more than twice as wide between eyes as length at middle; pronotum more than twice as wide as long.

Color: Golden yellow, pronotum with three white spots on anterior margin, scutellum with white mottling, elytra with a white opaque appearance.

Female genitalia: Last ventral segment rather long, the posterior margin not strongly produced, gently convexly rounding.

Male genitalia: Valve about twice as long as preceding segment, posterior margin truncate or slightly produced; plates long, strongly curved, upturned, and laterally flared on apical third, heavily clothed ventrally with long spines and hairs. Of the male genital pieces, the lateral pygofer processes in ventral view are constricted and again enlarged near apex, in lateral view there is a ventral, slender, finger-like process; styles tapered at apex and strongly divergent; spines of tenth segment long and broadly curved.

Described from a series of 13 male and 13 female specimens from Vancouver, B. C., in the collection of E. D. Ball, labeled "Livingston" and collected July, August, and September, 1896.

Holotype male, allotype female, and male and female paratypes in the E. D. Ball collection, Tucson, Ariz.; male and female paratypes in the DeLong collection, Columbus, Ohio, and the United States National Museum collection, Washington, D. C.

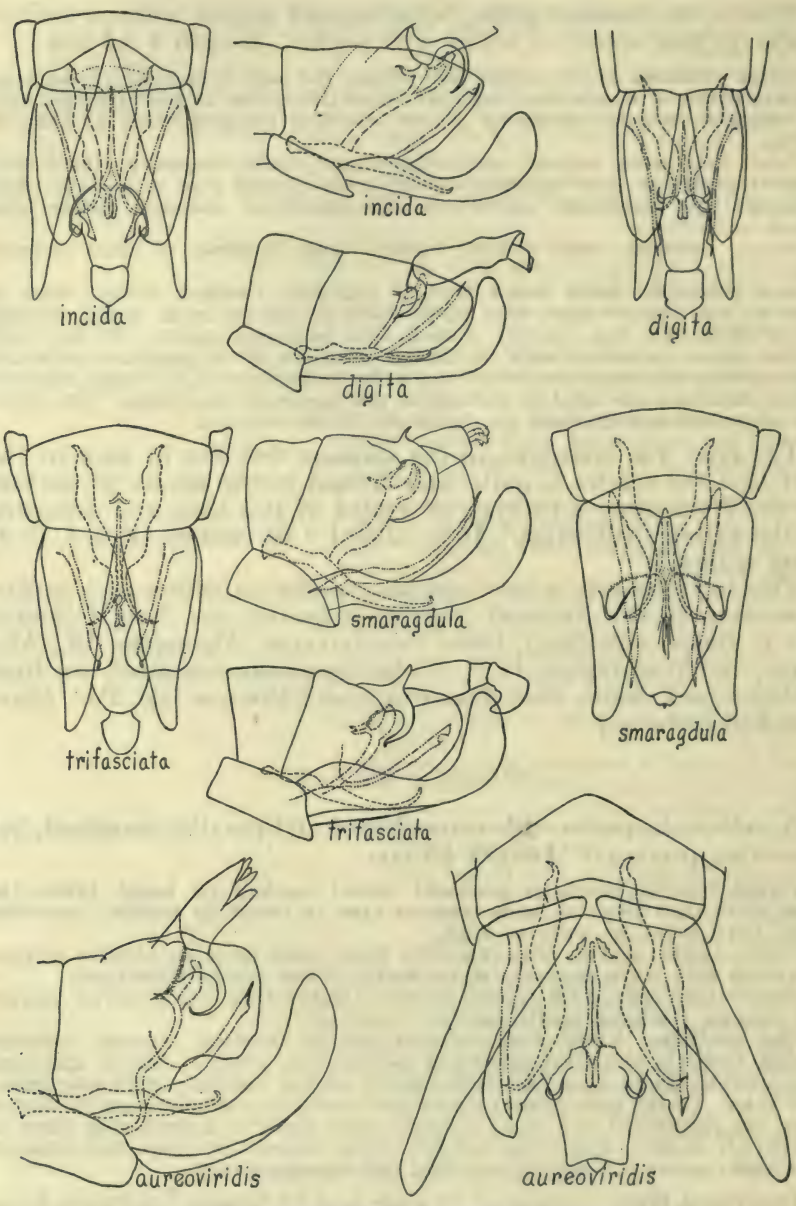

FIGURE 6.—Male genital pieces of species of Empoasca. ×50

EMPOASCA PATULA N. SP.

(Fig. 5)

Resembling *obtusa* in form and appearance, but with vertex more produced and with distinct internal genital structures. Length 3.5 to 4 mm.

Vertex broadly rounded but considerably produced, extending almost half its length beyond anterior margins of eyes, only a little longer on middle than next the eyes, more than twice as broad as long; pronotum more than twice as long as vertex.

Color: Dull green washed with yellow, scutellum with basal angles sometimes orange; elytra pale green, subhyaline, sometimes their inner margin with a narrow pencil line black.

Female genitalia: Last ventral segment very strongly produced, apex narrowed and almost angled, convexly rounded from near base.

Male genitalia: Valve narrowed posteriorly and with posterior margin gently produced; plates rather broad at base, gradually narrowed to bluntly rounded tips, posterior half upturned and flaring, heavily clothed ventrally with long black spines. Of the male genital pieces, the lateral processes of the pygofers are slender, tapered at the apex, and sinuate. This is the character by which it can be distinguished from *obtusa* and closely related forms. In ventral view the styles are more curved outwardly, both basally and apically, than those of *obtusa*. Chitinous spines of tenth segment more slender and elongated than in *obtusa*.

Described from a series of specimens collected at Dyersburg, Tenn., June, 1915 (DeLong); Orono, Fort Kent, and Portland, Me., June, 1913 (Osborn); and Harrisburg and several other localities in Pennsylvania in June and July (Sanders and DeLong).

Holotype male, allotype female, and male and female paratypes in author's collection, Columbus, Ohio. Paratypes in United States National Museum collection and collections of Herbert Osborn, Columbus, Ohio, and E. D. Ball, Tucson, Ariz.

EMPOASCA PATULA VAR. MAGNA N. VAR.

Appearing entirely distinct from *patula*, but with internal genitalia almost exactly like those of preceding form. Much larger in size and with western distribution. Length 4.5 mm.

Vertex not so greatly produced and appearing broader.

Color: Bright yellowish green, almost devoid of markings; three white spots on pronotum usually more or less conspicuous; usually with a broad white stripe on scutellum; elytra appearing opaque, veins at apex yellow, conspicuous.

Genitalia: Both internal and external structures, same as in *patula*.

This form occurs only in the West and may be an entirely different species in spite of the similar genital structures. Described from a series of 5 males and 22 females from Vancouver, B. C., collected in August and September, 1896, by Livingston. These are all in the collection of E. D. Ball.

Holotype male, allotype female, and male and female paratypes in the E. D. Ball collection, Tucson, Ariz. Paratypes in United States National Museum collection and in the author's collection.

EMPOASCA ALBOLINEA GILLETTE

Described by Gillette as an Empoasca in 1898 (*13*).

A rather strikingly colored species described from female specimens only, so the validity of the species can not be assured; probably it is closely related to *patula*. Length 3.5 mm.

Vertex strongly curved with about half its length produced beyond anterior margins of eyes, a little longer on middle than next the eyes, and more than twice as wide between eyes as length at middle.

Color: Vertex, pronotum, and scutellum orange yellow; vertex with a central white longitudinal stripe and a dash either side about half way to eye; pro-

notum with a pale line along anterior margin, a spot at middle on anterior margin, and an irregular blotch behind either eye white; usually a longitudinal white stripe across scutellum; elytra yellowish green, a whittish green stripe along commissural line, and claval vein broadly white; costal veins more greenish.

Genitalia: Female segment with posterior margin roundedly produced. Male unknown.

Known only by the type specimens from Douglas Co., Kans., and Illinois; and two female specimens, exactly like the types, which are in the collection of Herbert Osborn and were collected by him at Columbus, Ohio. Recorded as occurring on willow.

It is quite probable that this is only a highly marked color form of *obtusa*.

Type in United States National Museum.

EMPOASCA SALUTA N. SP.

(Fig. 5)

Resembling *obtusa* in general form and appearance. Length 3.5–4 mm.

Vertex almost parallel margined, slightly produced before anterior margins of eyes, more than twice as wide as long.

Color: Pale green tinged with white and yellow; elytra greenish, subhyaline.

Female genitalia: Last ventral segment with posterior margin roundedly produced.

Male genitalia: Plates long, triangular, tips upturned, ventral surface covered with heavy spines. Of the male genital pieces, in ventral view the lateral processes of the pygofers are long with hooked or sickle-shaped terminal processes. In lateral view these processes are rather broad to near the apex where they are rather abruptly constricted or notched on the ventral side to produce a dorsal fingerlike terminal process. Dorsal spines of tenth segment long and narrow with tips attenuated and directed ventrally.

Described from a series of 56 specimens labeled "Arizona" in the collection of C. F. Baker in the United States National Museum.

Holotype male, allotype female, and male and female paratypes in the United States National Museum.

EMPOASCA AUREOVIRIDIS (UHLER)

(Fig. 6)

Described by Uhler in 1877 as a Typhlocyba (*24, p. 474*).

In form and color resembling *obtusa*, uniformly green in color, and distinguished from *obtusa* chiefly by its larger size. Internal genitalia distinct. Length 5 to 5.5 mm.

Vertex parallel margined, only slightly produced beyond anterior margins of eyes, more than twice as wide as long; pronotum with prominent humeral angles, slightly wider than head and two and one-half times as long as head, posterior margin strongly concave between humeral angles; elytra very long.

Color: Yellowish green with irregular and variable mottling; vertex, pronotum, and scutellum usually washed with yellow and sometimes with pale median stripes or markings across pronotum and scutellum; elytra pale green, subhyaline.

Female genitalia: Last ventral segment strongly convexly produced, side margins deeply concavely indented on either side of central half, which is roundedly produced and slightly indented at middle, giving posterior margin a lobed appearance.

Male genitalia: Valve one-third longer than preceding segment, apex broad and almost truncate, slightly indented at middle; male plates long, turned

upward and flared at tips, apices rather broad and rounded, heavily armed ventrally with long white spines. Of the male genital pieces, the lateral processes of the pygofers in ventral view are rather abruptly tapered to the pointed apices; in lateral view dorsal margin straight, ventral margin enlarged near apex, then tapered to a sharply pointed apex; spines of tenth segment strongly curved anteriorly and inwardly.

A series of specimens from Colorado in the C. F. Baker collection, United States National Museum, are apparently this species. Other specimens examined in the collection of E. D. Ball are from Rico, Fort Collins, and Ward, Colo. Recorded as occurring upon willow.

Location of type unknown.

EMPOASCA AUREOVIRIDIS VAR. VITTATA HARTZELL

Described by Hartzell as *Empoasca vittata* 1923 (*18*).

In size and form agreeing with *aureoviridis* Uhler and distinguished only by the black stripe extending from the pronotum along the commissural line of the elytra to the apex. Length 5 mm.

Vertex almost parallel margined and only slightly produced before anterior margins of eyes.

Color: Pale green or yellowish with a brownish spot covering the median posterior two-thirds of the pronotum; this forms the anterior portion of a broad, brown stripe that extends across the scutellum and along the inner margins of the wings to the apex.

Genitalia: Female segment concavely produced to form prominent obtusely angled posterior margin. External and internal male genitalia agreeing almost exactly with those of *aureoviridis*. They can not be separated by any genital character.

Known only by a female from Stanford University, Calif., and a male from Colorado (author's collection) which agrees with the female in form and coloration.

Type in the author's collection.

EMPOASOA SMARAGDULA (FALLEN)

(Fig. 6)

Described by Fallen as a Cicada in 1806 (*8, p. 53*) and redescribed as *viridipes* by Curtis in 1837 (*3, p. 640*).

Usually distinguished from the other species of the genus by the black stripe extending from the posterior portion of the pronotum to the apex of the clavus along the commissural line. Length 4 mm.

Vertex broadly rounded, parallel margined, slightly produced before anterior margins of eyes; pronotum three times as long as vertex.

Color: Green to yellow, marked with dark brown or black; vertex usually green to golden yellow; pronotum with central portion brownish and lateral portions paler; scutellum brownish, together with dark portion on pronotum forming the stripe which extends along the elytra; elytra greenish, a broad brownish stripe extending to apex of clavus, basal third or fourth of elytra smoky; face and beneath yellowish to green.

Female genitalia: Last ventral segment long, convexly rounded to about half its length, then concavely rounded to form a blunt, rounded apex, the concaved portion showing a rounded indentation at either side.

Male genitalia: Valve rounded and sloping to a bluntly angled posterior margin; plates long, tips twisted laterally and curled, apices appearing pointed but broadly rounded and protruding upward, heavily set with black spines. Of the male genital pieces, the styles are more slender than in allied species and rather strongly curved outward at apex, the lateral processes of the pygofers are long and gradually tapered to the pointed apices, and the spines of the tenth segment are long and rather strongly curved.

The United States National Museum collection contains a series of specimens from Colorado (C. F. Baker collection) and two specimens from the Michigan Agricultural College. Other specimens examined are from Penfield, Pa. (author's collection). This insect is common on willow, and Gillette has recorded it on *Crataegus rivularis*.

Location of type unknown.

EMPOASCA TRIFASCIATA (GILLETTE)

(Fig. 6)

This species was described by Gillette as *Empoasca trifasciata* in 1898 (*13*), and has remained as a good species.

Easily separated from all the other species of the genus by the three transverse bands of black. Length 4 mm.

Vertex broadly rounded, scarcely produced beyond anterior margins of eyes, twice as wide between eyes as length at middle; pronotum more than twice as long as vertex. Elytra long, abdomen reaching to about apex of clavus.

Color: Pale green; vertex, upper portion of face, and anterior part of pronotum frequently tinged with orange; eyes dark; a broad band across posterior half of pronotum, a narrow one across elytra at middle of clavus, and a much broader one across apex of elytra dark brown to black.

Female genitalia: Last ventral segment slightly roundedly produced and slightly indented at middle.

Male genitalia: Valve produced and strongly rounded; plates long and tapering, heavily covered with white and black spines and usually recurved at the tips. Of the male genital pieces, the styles (in ventral view) are strongly constricted and narrowed about one-third the distance from the apex, forming long, slender, outwardly curved apices; the oedagus is long and narrow; the lateral processes of the pygofers in ventral view appear strongly constricted and twisted at the apex, in lateral view strongly notched just before the apex; the spines of the tenth segment are rather broad and thick.

It was described from specimens from Douglas County, Kans., Champaign, Ill., and Ames, Iowa. Other specimens in the National Museum are from St. Louis, Mo., and Chicopee, Mass. Specimens in E. D. Ball's collection are from Ames, Iowa, and Fort Collins, Colo. A common species on Carolina poplar (cottonwood).

Type in United States National Museum collection.

EMPOASCA DIGITA N. SP.

(Fig. 6)

Resembling *obtusa* in size and general appearance but with vertex, pronotum, and scutellum frequently black and with distinct internal genital characters. Length 4 mm.

Vertex broadly, roundedly produced about one-half its median length beyond anterior margins of eyes, parallel margined, almost three times as wide between eyes as length at middle; pronotum three times as long as vertex, humeral angles produced and prominent, pronotum wider than head including eyes.

Color: Green, sometimes pale, vertex frequently washed with brown; pronotum and scutellum frequently dark brown to black with a few pale areas; elytra frequently with a narrow black line along inner margin.

Female genitalia: Last ventral segment about four times as long as preceding, strongly produced and roundedly narrowed to blunt apex.

Male genitalia: Valve about two and one-half times as long as preceding segment, broad and slightly roundedly produced posteriorly; plates rather long with apical half upturned and laterally curled and flared, apices rather broadly rounded. Of the male genital pieces, the lateral processes of the

pygofers in ventral view are long and slender each with a slender fingerlike process on the outer margin; in lateral view they are tapered to a pointed apex; the styles in ventral view are very slender and strongly curved outwardly; the spines of the tenth segment are broad and not strongly curved.

Described from a series of seven female and three male specimens collected by R. D. Bird at Birtle, Manitoba, in July and August, 1928, and sent to the author for identification.

Holotype male, allotype female, and the paratypes male and female in the author's collection. Female paratypes in United States National Museum collection, Canadian National collection, Ottawa, Canada, and collection of E. D. Ball.

EMPOASCA COPULA N. SP.

(Fig. 7)

Superficially resembling *pulchella* because of the banded appearance, but larger, more robust, and definitely belonging to the *clypeata* group. Internal genitalia distinct. Length 3.75 mm.

Vertex parallel margined, produced about one-third its length before anterior margins of eyes, more than twice as wide between eyes as length at middle.

Color: Whitish to gray, marked with brown and tinged with golden yellow; vertex mostly golden yellow; pronotum brown, anterior margin with a narrow white area, lateral margins mottled; scutellum dark brown, apical third paler; elytra with a dark band across middle of clavus extending to costal margin and a band across apex extending forward to apex of clavus; face golden yellow with a median white stripe; lorae white.

Male genitalia: Valve about two and one-half times as long as preceding segment, posterior margin slightly produced and broadly angled; plates triangular, about twice as long as valve, gradually tapered and set with heavy spines. Of the male genital pieces the oedagus is very similar to that in other closely related species, the styles are similar but more slender than in related species and gradually tapered to the rather blunt divergent apices, and the lateral processes of the pygofers in lateral view have a distinct terminal dorsal finger process which appears on the inner terminal portion in ventral view. These latter processes easily distinguish this species.

Described from two male specimens collected in Wisconsin in 1916 by the author. One was taken at Merrillan August 3 and the other at Ladysmith August 9.

Holotype male and paratype male in the author's collection.

Described by Gillette in 1898 (*13*).

EMPOASCA LIVINGSTONI GILLETTE

(Fig. 7)

One of the largest species of the genus. Brownish in color or green with longitudinal brown stripe and apical band of black. Length 5 mm.

Vertex almost parallel margined, only slightly produced before anterior margins of eyes and more than twice as wide as middle length; pronotum two and one-half times as long as vertex, deeply concave posteriorly, lateral angles rounded; elytra greatly exceeding abdomen.

Color: In well-marked specimens the color is greenish or yellowish green; posterior portion of vertex dark brown or black; central half of pronotum black; scutellum and a rather broad stripe extending about half the length of elytra along the commissural line and a broad band covering apical cells of elytra black; other specimens are entirely dark brown to black.

Female genitalia: Last ventral segment strongly produced, lateral margin deeply concavely notched on either side about halfway to apex, forming a produced lobe which is about one-half the width of the segment.

Male genitalia: Valve about three times as long as preceding segment, slightly concave, almost truncated; plates long but appearing short because of their upturned and flaring tips, the apices of which are broadly rounded, heavily clothed ventrally with long white spines. Of the male genital pieces, the styles are heavy at base, greatly narrowed at about half their length, and divergently produced, each with a heavy tuft of long hairs on the dorsal side which extends well into the genital chamber; the lateral processes of the pygofers in ventral view are rather heavy, slightly enlarged before apex, then rather abruptly pointed, in lateral view appearing slightly enlarged and with a terminal ventral finger process; the spines of the tenth segment rather long and broadly curved.

The cotypes in the Museum are from Easton, Wash., and the other specimens in the collection are from Colorado and from Vancouver, B. C. A series of specimens in the collection of E. D. Ball are from Vancouver, B. C., and were collected by Livingston in July and August, 1896.

Cotypes in United States National Museum.

EMPOASCA CLYPEATA GILLETTE AND BAKER

(Fig. 7)

Described by Gillette and Baker in 1895 (*14, p. 108*).

Similar in size and form to *obtusa* but usually pale to dark brown in color. Internal genitalia distinct. Length 4 mm.

Vertex broadly rounded, produced about one-third its length beyond anterior margins of eyes, almost one-fourth longer on middle than next eye, more than twice as wide as long; pronotum more than twice as long as vertex; elytra greatly exceeding abdomen.

Color: Yellowish brown, frequently tinted with dull green, posterior portion of pronotum darker; elytra brownish subhyaline, veins yellowish; beneath yellowish with variable brown markings.

Female genitalia: Last ventral segment strongly produced, sides sloping to pointed apex which is blunt at tip.

Male genitalia: Valve with broad, slightly angled apex; plates compressed laterally and upturned at tips, heavily armed ventrally with long dark spines, apices rounded and flaring. Of the male genital pieces, the lateral processes of the pygofers are long, slender, and tapered to acute tips in lateral and ventral views; the spines of the anal tube ring (tenth segment) are heavy at the base, somewhat right angled, and are not so long or slender as in *annella;* and the styles are rather slender and rather strongly recurved.

There is a large series of specimens from Colorado (C. F. Baker collection) and a small series from California. Recorded as occurring on willow.

The type, in the United States National Museum, is from Colorado.

EMPOASCA CLYPEATA VAR. ANNELLA HARTZELL

(Fig. 7)

Described by Hartzell in 1923 (*18*) as a new species.

Resembling *clypeata* in form and appearance, but with a little different coloration and internal genital structures slightly different. Length 4.3 to 4.5 mm.

Vertex broad and almost parallel margined, slightly produced before anterior margins of eyes, more than twice as wide as long.

Color: Dark brown, vertex sometimes pale, pronotum and scutellum frequently with a light median stripe ending in a white spot on disk of scutellum; elytra appearing striped, brown tinged with green and with claval suture heavily, broadly brown and with a broad stripe on the corium, apical fourth brown.

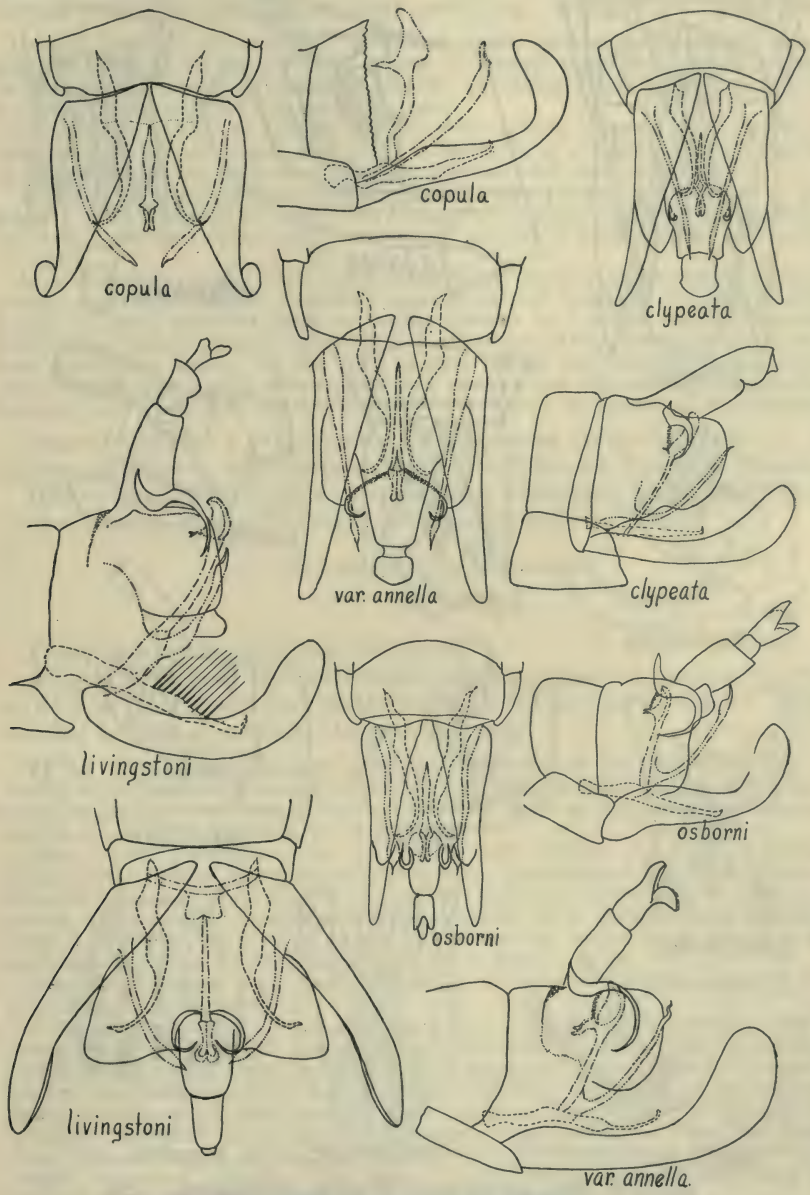

FIGURE 7.—Male genital pieces of species of Empoasca. ×50

Genitalia: External genitalia not differing from *clypeata*.

The internal genital characters in the male which distinguish this variety are the waved or sinuated tips of the lateral processes of the pygofers and the long, slender, broadly curved spines of the anal tube ring which extends both ventrally and inwardly into the genital chamber.

Possibly this may prove to be a distinct species, but with our present material it is well within the range of probable variation and would seem to be only a color form.

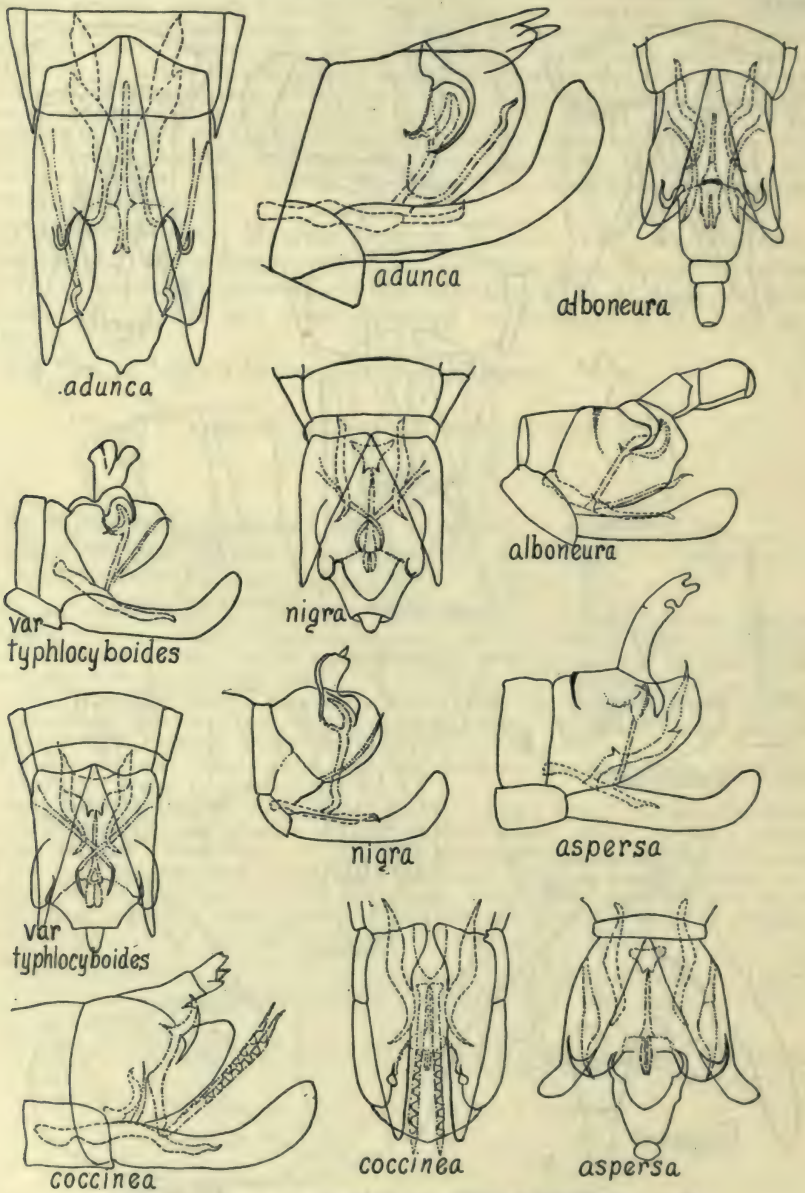

FIGURE 8.—Male genital pieces of species of Empoasca. ×55

A large series of specimens from Colorado (C. F. Baker collection) is in the United States National Museum. There is also a series of specimens in the collection of E. D. Ball, labeled "Vinta Pam'l."

Type in the author's collection.

EMPOASCA ADUNCA N. SP.

(Fig. 8)

Resembling *obtusa* in form and appearance but more yellowish brown and with distinct internal genitalia. Length 4.2 to 4.5 mm.

Vertex broadly rounded and produced about one-third its length before anterior margins of eyes, slightly longer on middle than next the eyes, twice as wide between eyes as length at middle; pronotum twice as long as vertex, humeral angles rounded off, not prominent.

Color: Pale green to brown, tinged with yellow, usually pale brown in appearance; pale specimens with three white spots or areas on anterior margin of pronotum; elytra with inner margins marked with a narrow line.

Genitalia: In external appearance very similar to those of the others of this group. Female genitalia: Last ventral segment strongly produced and rounded, concavely notched either side of central produced third which is rounded at apex.

Male genitalia: Valve more than three times as long as preceding segment, lateral margins rounded, posterior margin almost truncate, frequently with a pair of small rounded teeth at middle formed by a slight median incision; plates long, apical portion upturned and curved laterally, heavily clothed with long spines and hairs. Of the male genital pieces, the internal genital structures which will easily distinguish this species are the shallow hooks bent laterally and anteriorly on the apices of the lateral processes of the pygofers.

Described from a large series of specimens from Colorado (C. F. Baker collection) which are in the United States National Museum.

Holotype male, allotype female, and paratypes male and female in the United States National Museum collection.

EMPOASCA OSBORNI HARTZELL

(Fig. 7)

Described by Hartzell in 1923 (*18*).

A pale brownish species smaller than *clypeata* and occurring on willow in the eastern and southern parts of the United States. Form similar to that of *obtusa*. Length 3.5 mm.

Vertex more produced than in *clypeata*, produced almost one-half of its length beyond anterior margin of eyes, about twice as wide as long and slightly longer at middle than next the eye. Pronotum twice as long as vertex, humeral angles not greatly produced or prominent.

Color: Dull yellowish green to brown with darker markings sometimes washed with orange on vertex and pronotum; frequently a pair of dark brown blotches extending from middle toward the eye upon either side of margin of vertex above ocelli; pronotum heavily mottled with dark brown; scutellum with a pale area at middle; elytra pale brownish, subhyaline, venation conspicuous on posterior half; beneath yellow to green.

Female genitalia: Last ventral segment strongly roundedly produced to a prominent rounded apex.

Male genitalia: Valve twice as long as preceding segment, posterior margin broad, gently sloping and angled, slightly indented at center; plates appressed and upturned at tips, heavily armed with long black spines. Of the male genital pieces, the styles are long and slender, the lateral processes of the pygofers have rather abruptly broadened, rounded portions near the apex and are then abruptly narrowed to the slender attenuated tips (ventral view). In lateral view these processes are narrow, enlarged at apex, and terminate in a ventral caudal fingerlike process. The spines of the tenth segment are long and strongly curved, and their apices are directed anteriorly.

The type specimens are from Marietta, Ohio, collected in September, 1905. A series of specimens in the author's collection were collected from willow at Knoxville, Tenn., in April, June, and September, 1917, by W. B. Cartwright.

Type in Osborn collection.

THE SUBGENUS HEBATA NOV.

Smaller in size than species of the subgenus Kybos and with vertex bluntly rounded or angled. Vertex appearing broad, rounded, but not parallel margined.

Type of subgenus, *nigra* Gillette and Baker.

KEY TO THE SPECIES OF THE SUBGENUS HEBATA NOV.

(*nigra-aspersa* group)

A. Color black, or pale green with black or red markings. Occurring on sagebrush. Less than 3 mm. in length.
  B. Rather uniformly black in color ..... *nigra*, p. 32
  BB. Pale with black or reddish to brownish markings.
    C. A black spot on scutellum and posterior portion of pronotum and a spot on commissural line just before apex of clavus ..... var. *nigroscuta*, p. 33
    CC. Without black markings but marked with red or reddish brown.
      D. Pale with broken reddish stripes between veins of elytra ..... var. *typhlocyboides*, p. 33
      DD. White to gray with red stripes as above but intensified by smoky bands across middle of elytra and apical cross veins ..... var. *pulchella*, p. 34
AA. Pale to dark green or tinted with red on vertex and pronotum, but without spots or lines of red or black coloration. Usually 3 mm. or slightly more in length.
  E. Dark green or reddish in color. Oedagus of male with a pair of long processes extending caudally and dorsally from basal end. Occurs on pine ..... *coccinea*, p. 35
  EE. Usually paler or brighter green. Oedagus of male without processes arising from basal end.
    F. Elytra pale green, usually mottled with smoky, giving it a mosaic appearance. Male lateral processes of pygofers strongly curved and tapered to acute tips. (Figs. 2 and 8) ..... *aspersa*, p. 34
    FF. Elytra dull green, veins pale, giving it a striped appearance. Male lateral processes of pygofers slightly enlarged near apex and rather abruptly pointed. (Fig. 8) ..... *alboneura*, p. 35

SPECIES OF THE SUBGENUS HEBATA NOV.

EMPOASCA NIGRA GILLETTE AND BAKER

(Fig. 8)

Described by Gillette and Baker in 1895 (*14, p. 108*).

A small black species with blunt head, occurring on sagebrush. Length 2.5 to 2.75 mm.

Head blunt and rounded, produced more than one-half its length beyond anterior margins of eyes, one-third longer on middle than next the eye, almost twice as wide as long; pronotum more than twice as long as vertex, head wider than pronotum, humeral angles not produced laterally; elytra rather short, about three and one-half times as long as broad.

Color: Dark brown to black with varying paler and darker areas; elytra usually with a lighter area just before apical cross veins, apical fourth usually subhyaline; beneath dark brown or black.

Female genitalia: Last ventral segment rather long, posterior margin somewhat produced and angularly rounded.

Male genitalia: Valve broad at apex and truncated; plates about four times as long as wide at base, slightly convexly rounded to what appear to

be pointed apices because the apical fourth is upturned. Of the male genital pieces, the styles are short with the apices curved outwardly; the lateral processes of the pygofers long and slender, normally crossing each other near tips and with apices on opposite side of oedagus from base as seen in ventral view; the spines of the tenth segment rather heavy and rather well curved near apices.

The type and a series of specimens in the National Museum are from Colorado (C. F. Baker collection). Recorded from sagebrush (*Artemisia tridentata*).

Type in United States National Museum.

EMPOASCA NIGRA VAR. TYPHLOCYBOIDES GILLETTE AND BAKER

(Fig. 8)

Described by Gillette and Baker in 1895 as *Empoasca typhlocyboides* (*14, p. 110*) and redescribed by Gillette as *E. robusta* in 1898 (*13*).

Size and form same as those of *nigra* and with the same external and internal genital characters, but with different color and markings. Length 2.5 to 2.75 mm.

Color: Pale yellowish to milky white with dull reddish markings which may vary in pattern and intensity; vertex usually yellowish; pronotum and elytra ranging from pale yellow to milk white, in well-marked specimens with two longitudinal lines extending from ocelli across vertex and pronotum to basal angles of scutellum, pale reddish or yellowish; elytra frequently with dull reddish mottling between wing veins or sometimes with the anterior half showing only a few reddish markings on a milky white background and with a somewhat definite band across middle of elytra; beneath pale.

Genital characters: Exactly as in *nigra*.

The type specimens of *robusta* are only very pale female specimens of *typhlocyboides* and can not be distinguished from pale specimens in this latter type series.

Specimens in the collection of E. D. Ball are from Salt Lake City and Marysvale, Utah, June, 1906, and from Gunnison, Colo., August, 1899. Occurs abundantly on sagebrush (*Artemisia tridentata*).

Type in United States National Museum collection, from Nevada Co., Colo.

EMPOASCA NIGRA VAR. NIGROSCUTA GILLETTE AND BAKER

Described by Gillette and Baker as an Empoasca in 1895 (*14, p. 108*).

Agreeing with *nigra* in general size, form, and genital structures, but with different color markings. Length 2.3 to 2.8 mm.

Color: Yellowish or milky white with dull reddish markings as in *typhlocyboides*, but differing from it by a black spot covering the scutellum and posterior portion of pronotum just before it and another black spot along commissural line just before clavus; abdomen black above and pale beneath.

External and male internal genitalia same as in *nigra*.

Specimens in the collection of E. D. Ball are from Marysvale, Salt Lake City, and Helper, Utah, Reno, Nev., and Penticton, British Columbia (Downs). An abundant species on sagebrush (*Artemisia tridentata*).

Type in United States National Museum (C. F. Baker collection) with other specimens from Colorado.

EMPOASCA NIGRA VAR. PULCHELLA GILLETTE AND BAKER

Described by Gillette and Baker as an Empoasca in 1895 (*14, p. 109*).

Very similar to *typhlocyboides* in coloration and resembling the other members of the *nigra* group in size and form. No male specimens are in the type set, nor have any been available for study, but it is undoubtedly only a color variety of *nigra*. Length 2.75 mm.

Ground color as in *typhlocyboides*, pale yellowish to milky white; vertex and pronotum with vermiculate reddish brown markings; elytra milky white with the markings of *typhlocyboides*, but intensified by a darker or smoky area just back of scutellum almost forming a band in some specimens, a smoky band across elytra just before apex of clavus, and a third which is quite distinct across apex of elytra, especially intensified at the cross veins of the apical cells; veins at apex of wing pale and conspicuous.

No male specimens have been examined. Occurs on sagebrush (*Artemisia tridentata*).

Type and a series of specimens from Colorado are in the United States National Museum collection.

EMPOASCA ASPERSA GILLETTE AND BAKER

(Figs. 2 and 8)

Described by Gillette and Baker in 1895 (*14, p. 107*). Gillette's later citation of this species as a synonym of *tessellata* Fieber was in error, according to Van Duzee (*26, p. 705*).

A small, green, blunt-headed species, in general size and appearance resembling *alboneura*, but with different coloration and genital characters. Length 3 mm.

Vertex bluntly rounded, produced more than half its length beyond anterior margins of eyes, not twice as wide as long; pronotum about one and one-half times as long as vertex; elytra rather short.

Color: Vertex, pronotum, and scutellum yellowish to pale green, varying in intensity and without definite markings; elytra pale green, usually entirely mottled with smoky, giving it a sort of mosaic appearance; veins light green, conspicuous.

Female genitalia: Last ventral segment roundedly produced.

Male genitalia: Valve with a V-shaped notch on posterior margin; plates broad at base, tapering to pointed tips, which are usually upturned; almost four times as long as width at base. Of the male genital structures, the styles are slightly enlarged and bent outward near the middle, and the tips are divergent; the lateral processes of the pygofers are unique by their inflation or broadening on the inner margins near their middle and then concave, narrowing to long, curved, attentuated apices. In lateral view they are even more striking by their irregular shape and especially by the ventral incision about one-third the distance from the apex. The spines of the tenth segment are short, broad, and scarcely rounded.

A large series of specimens from Colorado (C. F. Baker collection) and two specimens from Utah (Knowlton) are in the National Museum collection. Specimens in the collection of E. D. Ball are from Salt Lake City, Thompson, Cisco, Monroe, Richfield, Provo, Joseph, Marysvale, Logan, and Helper, Utah; from Pasadena, Ontario, Riverside, Salinas, Tia Juana, Cabazon, Santa Barbara, and Spreckles, Calif.; and from Gunnison, Fort Collins, Palisade, and Grand Junction, Colo.

A western species recorded by Gillette from Bigelovia and sagebrush (*Artemisia tridentata*).

Type in United States National Museum.

EMPOASCA ALBONEURA GILLETTE

(Fig. 8)

Described by Gillette in 1898 as *Empoasca alboneura* (*13*) and apparently redescribed as *E. tumida* in the same paper.

Easily distinguished from the other species of the genus by the light veins, color markings, and distinct genitalia. Length 3 mm.

Vertex strongly but bluntly angled, produced more than half its length beyond the anterior margins of the eyes, one-third longer on middle than next the eyes, not quite twice as wide between eyes as length at middle.

Color: Dull greenish; vertex with a median stripe and an oblique dash either side white; pronotum with three large pale spots on anterior margin; elytra dull greenish, veins pale and conspicuous, green color of elytra sometimes appearing tinted with brown.

Female genitalia: Last ventral segment with the posterior margin roundedly produced.

Male genitalia: Valve angularly notched; plates appearing tapered to pointed apices because of folded and upturned tips, about four times as long as width at base. Of the male genital pieces, the styles are narrow and are strongly curved inwardly at middle, then their apices diverge; the oedagus is enlarged and broad on apical half in ventral view; the lateral processes of the pygofers are convexly curved inward, the apices slightly broadened and concavely narrowed on outer margins to pointed tips (ventral view); in lateral view appearing almost straight and tapered to acutely angled, attenuated apices.

The cotypes in the National Museum collection are labeled "Riley, Kans."; "Horace, Kans."; and "Nevada County, Calif." The species was also described from a series of specimens from Mississippi. Other specimens in the collection are from Alabama, Colorado, Oregon, Virginia, District of Columbia, Los Angeles County, Calif., and Mexico. Specimens in the E. D. Ball collection are from Fort Collins, Trinidad, and Alder, Colo., Ravenna, Calif., Wells, Nev., and Tia Juana, Victoria, and Jalapa, Mexico.

A very common species, distributed almost throughout the United States on herbaceous plants.

Type in United States National Museum.

The male of *tumida* is unknown. However, female specimens of *tumida* can not be distinguished from the types of *alboneura* except by a slight variation in size. It is highly probable that they are the same. This probability is strengthened by the fact that one specimen in each type set was collected from plum at the same place and on the same day (Fort Collins, Colo., September 31). These data, together with the similar color and appearance, indicate very strongly that *tumida* is a synonym of this species.

EMPOASCA COCCINEA (FITCH)

(Fig. 8)

Described by Fitch as *Empoa coccinea* in 1851 (*11*).

A small green to reddish species common on pine. Distinguished from related species by the genitalia. Length 3.2 mm.

Vertex appearing bulbous, strongly roundedly produced about one-third its length beyond anterior margins of the eyes. About one-fourth longer on middle than next the eyes, almost twice as wide between eyes as length at middle. Pronotum about one and one-half times as long as vertex.

Color: Varying from dull green to rather bright red; when green, usually tinged with red. Elytra greenish or smoky subhyaline.

Female genitalia: Last ventral segment with posterior margin rather broadly roundedly produced, more than twice as long as preceding segment.

Male genitalia: Valve broadly rounded; plates broad at base, evenly tapered to pointed acute tips, about three times as long as basal width. Of the male genital pieces, the oedagus is unique among the species of the genus by the possession of a pair of long structures which extend slightly posteriorly and caudally from the base of the oedagus proper; the lateral processes of the pygofers are very short; the spines of the tenth segment are very broad, but tapered and slender on the apical fourth. By these characters it is easily distinguished from all the other species of the genus.

Specimens in the United States National Museum are from Pennsylvania (Wirtner), Arnold Arboretum, Boston, Mass. (Morrison), and from Maryland.

A common species on white pine and collected occasionally on other species of pine. Known only from the eastern and northeastern part of the United States and Canada. The known distribution apparently corresponds with the northern coniferous forest area.

Type in New York State Museum collection, Albany, N. Y.

THE SUBGENUS EMPOASCA WALSH

Vertex produced and strongly rounded or bluntly angled, length at middle usually about one-half width between eyes. Usually green or yellowish with white spots.

Type of subgenus, *fabae* Walsh.

KEY TO THE SPECIES OF THE SUBGENUS EMPOASCA WALSH

(*fabae* group)

A. Size small, less than 3 mm. in length. Male lateral processes of pygofers slightly inflated laterally near base, then narrowed, in lateral view with apical third curved sharply upward and then interiorly. (Fig. 9) ---------- *recurvata*, p. 38

AA. Larger, 3 mm. or more in length.

B. Size 4 mm. in length ---------- *snowi*, p. 39

BB. Less than 4 mm. in length.

C. Dull brownish red with white areolar spots; male lateral processes of pygofers long and slender; known only from California ---------- *rubida*, p. 39

CC. Sometimes with brownish banding on elytra but without reddish coloration. Mostly green or yellowish.

D. Male plates narrow at base, long and appearing almost parallel margined to near apex, about three and one-half times as long as basal width ---------- *barbara*, p. 40

DD. Male plates more triangular or broader proportionately at base.

E. Spines of chitinous ring around anal tube long and bifurcate at about two-thirds their length ---------- *bifurcata*, p. 40

EE. Spines of chitinous ring around anal tube single, not bifurcate.

F. Male lateral processes of the pygofers slender, practically straight, tapered and neither enlarged, curved, nor hooked near tips.

G. Color yellowish, marked with white, elytra strongly mottled or banded with brown or smoky, male processes rather heavy ---------- *birdii*, p. 41

GG. Pale green sometimes washed with orange, but without brownish coloration or banding of elytra.

H. Elytra with veins broadly white margined with green or smoky and with white spots on clavus and corium, dorsal spines with teeth on ventral margins ---------- *pallidula*, p. 42

HH. Elytra greenish without white veins, dorsal spines long without ventral teeth.
I. Elytra green with orange tint and marked with large white spots ---- *hamata*, p. 43
II. Elytra green without coloration or spotting.
J. Later processes of pygofers long and narrow ---- *filamenta*, p. 43
JJ. Lateral processes of pygofers shorter ---- var. *abbreviata*, p. 44
FF. Male lateral processes of pygofers enlarged before apex or with curved or hooked tips or with fingerlike projections.
K. Male lateral processes practically parallel margined, but broadly curved or bent near apex.
L. Elytra usually banded with black, male lateral processes with apices curved outwardly, spines of anal ring curved directly into genital chamber. (Fig. 10) ---- *vincula*, p. 44
LL. Elytra without dark markings, male lateral processes crossed, tips strongly curved inwardly, spines of anal ring directed ventrally and anteriorly ---- *deluda*, p. 46
KK. Male lateral processes not parallel margined at apex or with hooked or fingerlike processes.
M. Male lateral pygofer processes narrowed near middle and with long, tapering, terminal processes ---- *cerea*, p. 46
MM. Male lateral pygofer processes with terminal portions short and not tapered.
N. Male lateral processes narrowed and produced in fingerlike projections at apex (ventral view).
O. Male processes from ventral view roundedly inflated on inner margin, then gradually tapered to slightly curved attenuated apices ---- *fabae*, p. 47
OO. Male processes usually not inflated (ventral view), but rather abruptly narrowed to fingerlike apical projections.
P. Length 3.5 mm., male process rather abruptly narrowed near apex to outer thick fingerlike projections. (Fig. 10) ---- *abrupta*, p. 48
PP. Smaller, about 3 mm. in length, outer fingerlike projections very narrow and attenuate. (Fig. 10) ---- *erigeron*, p. 48
NN. Male lateral process decidedly curved or hooked at apex (ventral view).
Q. Apices of male lateral processes strongly curved or hooked with apex extending inwardly ---- *arida*, p. 49
QQ. Apices of male lateral processes with a short attenuated hook at apex (ventral view) and a more pronounced hook at apex (lateral view) ---- *solana*, p. 50

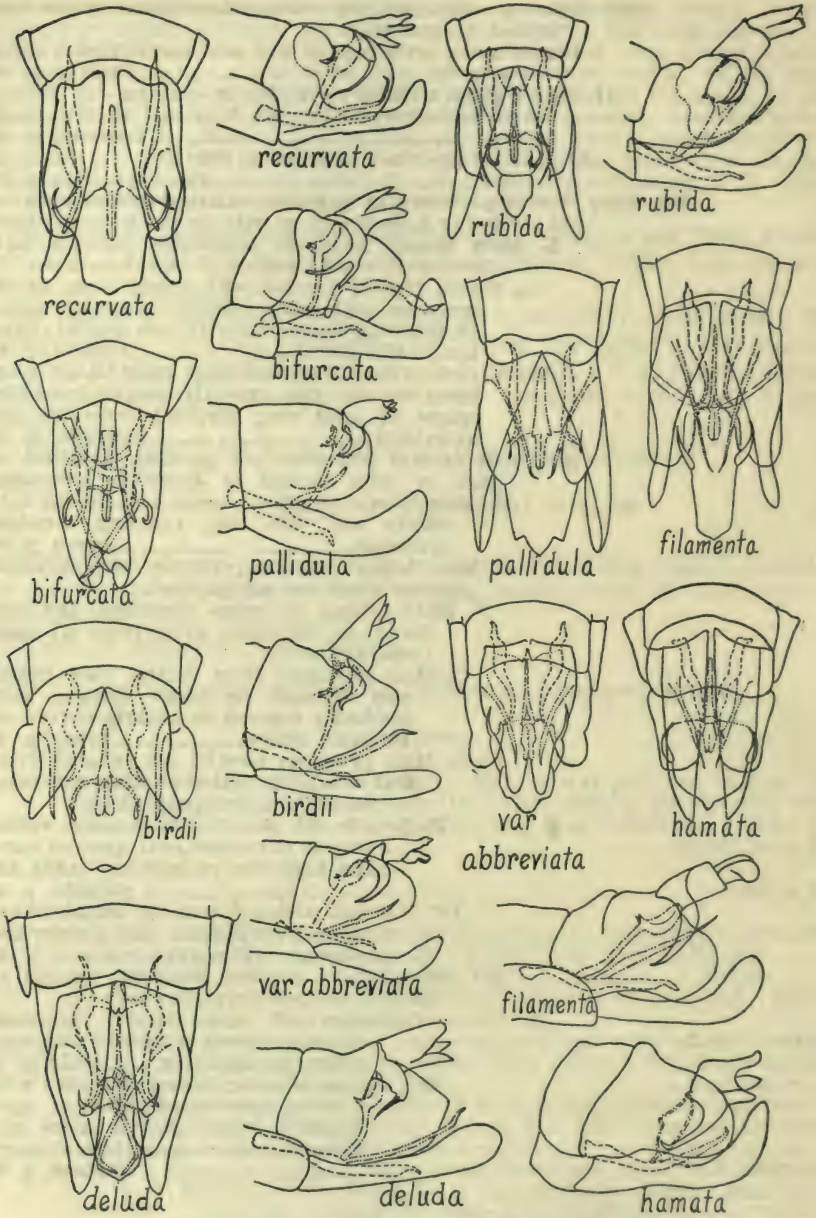

FIGURE 9.—Male genital pieces of Empoasca. ×55

SPECIES OF THE SUBGENUS EMPOASCA WALSH

EMPOASCA RECURVATA N. SP.

(Fig. 9)

A small, blunt-headed species with robust male plates and distinct internal genitalia. Length 2.75 mm.

Vertex strongly rounded, bulbous, produced about one-half its length before anterior margins of the eyes, about one-third longer on middle than next eyes,

about one-half wider between eyes than length at middle; pronotum one-half longer than vertex, humeral angles prominent, pronotum wider than vertex.

Color: Pale green washed with yellow; vertex with a pair of pale green spots just back of margin; pronotum with three white spots which may be somewhat fused on anterior margin of pronotum; elytra yellowish green, definitely clouded.

Genitalia: Male valve broad and concave on posterior margin; plates three times as long as valve, parallel margined at base, tapered near tip to acute apices which are slightly upturned. Of the male genital pieces, the styles are long, slender, and almost straight with the exception of the slender divergent tips; the lateral processes in ventral view are constricted near base then slightly enlarged, again constricted about the middle and produced as slender parallel margined apical portions which in lateral view are abruptly curved upward with the apex bent slightly forward; the spines of the lateral processes are heavy at the base and a long, slender, slightly curved portion arises from this and extends ventrally and anteriorly.

Described from two male specimens collected by the author at Clarksville, Tenn., July 13, 1915, and August 4, 1917.

Holotype male and paratype male in author's collection.

EMPOASCA SNOWI GILLETTE

Described by Gillette in 1898 (*13*).

Since this species is represented by a single female type specimen it has been rather difficult to place it among our known and more common species. Apparently it is rather closely related to *arida* and *abrupta*. Length 4 mm.

Vertex rather strongly angled and produced about one-half its length beyond anterior margins of eyes, about one and one-half times as wide as length at middle; pronotum about twice as long as vertex.

Color: Greenish marked with orange yellow; vertex with a blotch next either eye and a somewhat irregular band between eyes just above margin of vertex; pronotum orange yellow with a row of five white spots along anterior margin of vertex, the second and fourth smaller and located just behind the inner margin of each eye; elytra greenish subhyaline, claval vein appearing striped with yellow.

Female genitalia: Last ventral segment with posterior margin slightly roundedly produced, a rounded notch on either side of central half dividing segment into three lobes, a small produced and rounded lobe at either side and a much larger, broadly rounded one at middle which is a little more produced. This female segment seems different from that of any other species of the genus.

A single female specimen in the United States National Museum from Magdalena Mountains, N. Mex., August, 1894, taken by Snow, is the only known record of this species. In view of this fact it has been rather difficult to place it.

EMPOASCA RUBIDA N. SP.

(Fig. 9)

A blunt-headed species with dull reddish mottling and white areolar markings. Length 3–3.3 mm.

Vertex bluntly rounded, produced about one-half its length before the anterior margins of the eyes, one-third longer on middle than next the eyes, about one-third wider between eyes than length at middle.

Color: Dull brownish red with white markings; vertex with a median stripe, a pair of spots enveloping ocelli, a smaller one between each of these and the corresponding eye, and a pair on the base next the eyes white; pronotum with three large white spots on the anterior margin, a small pale area on each humeral angle, and a larger one on the disk; scutellum with a median pale stripe on basal half and a pale spot at either side near middle; elytra with the

claval suture, a spot at base, one at about middle of clavus, two large spots on corium along claval suture, one at tip of clavus, and the costal area milky white; apices somewhat smoky subhyaline, nervures pale.

Female genitalia: Last ventral segment with the posterior margin slightly angularly produced.

Male genitalia: Valve almost truncated, slightly concave at middle; plates rather narrow, more than three times as long as basal width, tips slightly upturned. Of the male genital pieces, the styles are almost straight, slightly enlarged near the middle and with apices slightly divergent; the lateral processes of the pygofers appear almost straight in both ventral and lateral views and are slender, gradually tapering to long, acute, attenuated tips; the spines of the tenth segment are rather long and broadly curved.

Described from a large series of about 50 male and female specimens in the collection of E. D. Ball, all taken in California. The localities represented are Hamilton, San Francisco, Oxnard, and Spreckles. These were collected from April to September, inclusive, during 1907, 1908, and 1912.

Holotype male, allotype female, and male and female paratypes in the E. D. Ball collection, Tucson, Ariz. Paratypes in United States National Museum collection and author's collection, Columbus, Ohio.

EMPOASCA BARBARA HARTZELL

Described by Hartzell in 1923 (*18*).

A long, slender species with strongly produced head and long, slender male plates. Length 3.5 mm.

Vertex produced more than half its length beyond anterior margins of the eyes, more than one-third longer on middle than next the eyes, one-half wider between eyes than length at middle; pronotum twice as wide as long, humeral angles prominent.

Color: Dull greenish with variable pale markings; vertex, pronotum, and scutellum tinged with brown.

Male genitalia: Plates appearing long and slender, similar to those of the *maligna-atrolabes* group. Since so few specimens are known no material has been available for working out the internal genitalia.

Known only from male specimens collected in a pine grove at Pacific Grove, Calif., by Harold Morrison, in May, 1915.

Type in the Morrison collection, United States National Museum.

EMPOASCA BIFURCATA N. SP.

(Fig. 9)

A bright green species with yellow head, which has been confused with *fabae* and the European *flavescens* and has been placed under both names. It differs in having the head more produced, different genitalia, and a brighter green color. Length 3.2 to 3.5 mm.

Vertex produced more than half its length before the anterior margins of the eyes, almost one-half longer on middle than next eyes, one-half wider between eyes than middle length; pronotum twice as long as vertex.

Color: Bright green, vertex golden yellowish mottled with paler yellow around the ocelli and posterior to them; pronotum greenish, disk golden yellow, three large white spots on anterior margin of pronotum; scutellum with central white portion; elytra bright green, apices not colored, subhyaline, veins green.

Female genitalia: Last ventral segment with posterior margin roundedly produced.

Male genitalia: Valve concavely rounded; plates long with apical third upturned, frequently separated exposing styles, plates appearing from beneath short and broad. Of the male genital pieces, the lateral processes are very long and vermiculate, curving upward and laterally crossing the process from the other side and curving back again at the apex where it is broadened, then narrowed to form a sharp apex; the styles are almost straight; the spines of the tenth segment are broad, curving downward and anteriorly, and have a pair of long, divergent, fingerlike processes which are at least one-third the length of these chitinous spines.

The species is named "*bifurcata*" because of the bifurcate chitinous spines which are so conspicuous on each side of the chitinous anal ring (tenth segment). This is the only species known to have this type of spine.

Described from a series of more than 100 specimens ranging from Wisconsin and northern Pennsylvania to Miami, Fla. North East, Harrisburg, Hartstown, Cheswick, Landisburg, New Bloomfield, and many other localities in Pennsylvania are represented by material at hand collected by J. G. Sanders and the author. Specimens from Somerville, N. J., were collected by Professor Sanders also. A large series of specimens from Miami and Paradise Key, Fla., were collected by the author. Two specimens in the E. D. Ball collection are from Osceola, Wis., collected July 22, 1917.

Paratype specimens in the United States National Museum collection are from Agricultural College, Miss., Maryland, Kansas, Massachusetts, Alabama, and the District of Columbia, all in the C. F. Baker collection, and specimens from shrubs, Arnold Arboretum, Boston, Mass. (Morrison), and from Texas and Louisiana collected from tansy and other herbaceous plants. This is apparently a very common species throughout the eastern part of the United States.

Holotype male, allotype female, and paratype male and female in Sanders and DeLong collection, Columbus, Ohio. Paratypes in United States National Museum, the Canadian National collection, and the private collections of Herbert Osborn, Columbus, Ohio, and E. D. Ball, Tucson, Ariz.

EMPOASCA BIRDII GODING

(Fig. 9)

Described by Goding in 1890 (*15*) and treated as a variety of *Empoasca flavescens* by Gillette in 1898 (*33*), it has proved to be a good species and apparently is not closely related to *flavescens*. This species was apparently redescribed in 1898 by Gillette (*13*) from a series of specimens taken from cotton and which had been placed in alcohol before being mounted, so the green color had entirely disappeared leaving pure white insects which were described as *pallida*. Some of the specimens in the type series are apparently *fabae*, but the type is undoubtedly *birdii*.

Apparently rather closely related to the *fabae* group, but rather easily distinguished from them by the coloration and by the distinct genital characters. Length 3.3 mm.

Vertex rather broadly roundedly produced almost one-half its length beyond anterior margins of the eyes, about one-third longer on middle than next the

eyes, more than one-half wider between eyes than length at middle; pronotum twice as long as vertex; elytra usually rather long and narrow.

Color: Usually pale yellow marked with white or pale brown; vertex with a pale area around either ocellus, a median longitudinal line, and an oblique dash either side near eye, the remainder rather orange yellow; pronotum with three pale spots on anterior margin, a median spot, and one behind either eye; scutellum with a pale median-longitudinal band; elytra mottled and banded with brown or smoky, leaving pale areas along costa and at apex of clavus.

Female genitalia: Last ventral segment slightly produced, appearing keeled and angled at middle.

Male genitalia: Valve broad, concavely rounded between prominent lateral angles; plates broad at base, triangular, tapered to acute tips about two and one-half times as long as basal width. Of the male genital pieces, the lateral processes of the pygofers are almost straight, but not tapered to slender acute apices; the spines of the tenth segment are broad, rather strongly curved, and narrowed at apex.

Described from Illinois. Specimens in the United States National Museum collection are from Rutland, Ill. (Goding), Colorado, New York, Massachusetts, and Vancouver, British Columbia. Specimens in the E. D. Ball collection are from Franconia, N. H., and Kansas City, Mo. Specimens in the author's collection are from Columbus, Trinway, and Wooster, Ohio, and Indianapolis, Ind.

It breeds upon some of the common weeds, especially pigweed, and is found abundantly in cultivated fields where these weeds occur, but apparently it is not a pest of cultivated plants.

The specimens from Illinois in the United States National Museum are apparently the cotypes.

EMPOASCA PALLIDULA N. SP.

(Fig. 9)

A pale-green species with blunt head and many white areas upon the elytra. Length 3.5 mm.

Vertex bluntly angled and produced more than half its length before the anterior margins of the eyes, about one-third longer on middle than next eye and more than one-half wider between eyes than length at middle; pronotum about twice as long as vertex and with humeral angles prominent.

Color: Yellowish to pale green with white markings; vertex tinged with yellow, frequently marked with white spots; pronotum pale green with variable white markings; elytra pale green, the veins broadly white, two white spots on clavus, one on corium, and one before cross vein or inner apical cell, veins margined with green or smoky.

Female genitalia: Last ventral segment long with posterior margin angularly produced from prominent lateral angles to roundedly produced apex.

Male genitalia: Valve more than twice as long as preceding segment, truncated behind and gently rounded on either side to a shallow central notch; plates triangular, tapered to pointed apices, about three times as long as basal width. Of the male genital pieces, the styles are rather short, slightly broader at middle, and with both ends curved outwardly; oedagus broad; lateral processes almost straight and narrow, apices attenuated and turned inward; spines broad and rather short, narrowed at apex and with ventral apical portion serrate.

Described from nine female and six male specimens, all collected at Sabino Canyon, Ariz., June 29, 1919, by W. D. Edmondston.

Holotype male, allotype female, and paratypes male and female in author's collection. Paratypes in United States National Museum collection and in the private collection of E. D. Ball.

EMPOASCA HAMATA N. SP.

(Fig. 9)

Pale green washed with orange and marked with white. Length, 3 mm.

Vertex more than one-third wider between eyes than length at middle; pronotum almost twice as long as vertex.

Color: Vertex with median line, a basal spot next to either eye, and a spot enveloping each ocellus white; pronotum orange with three white spots on anterior margin, one at middle and one behind outer portion of each eye, also with white spots on apical third; elytra washed with orange, two spots anterior to claval vein, and two posterior, and claval vein milk white, apical third whitish subhyaline.

Female genitalia: Last ventral segment with posterior margin gradually, but rather strongly, produced and bluntly angled at middle.

Male genitalia: Valve angularly notched; plates more than three times as long as basal width, gradually tapered to acutely pointed apices which are upturned. Of the male genital pieces, the lateral processes of the pygofers are short and straight, constricted not far from base (in ventral view) and constricted again near apex, in lateral view the tips upturned; dorsal spines of tenth segment long, apical two-thirds narrowed, produced ventrally and anteriorly, and with tip turned upward.

Described from four specimens, three females and one male, collected at Mission Canyon, Santa Barbara, Calif., June 2, 1915, by Harold Morrison.

Holotype male, allotype female, and female paratypes in Morrison collection, United States National Museum.

EMPOASCA HAMATA VAR. ALBONOTA N. VAR.

Similar to *hamata*.

A small species with produced vertex and with elytra marked with white areolar spots. Male unknown. Length 3 mm.

Vertex more than one-third wider between eyes than length at middle; pronotum more than one-third longer than vertex; elytra exceeding abdomen by almost half their length.

Color: Vertex orange red, a broad median line, an oval oblique dash on either side not far from eye, a round spot enveloping each ocellus, and a small spot on margin next to either eye white; pronotum dull greenish, a broad median line, a small irregular spot behind each eye, and irregular vermiculate markings between these on anterior margin white; scutellum with a white median longitudinal line and a white spot half way along either side; elytra dull greenish tinged with orange yellow, a large elongate spot on anterior third of clavus, an oblique dash on posterior third, two large spots on corium just anterior to claval vein and venation of apex broadly white; face orange red with a median white stripe on upper half and a round spot halfway between each ocellus and antennal socket white.

Female genitalia: Last ventral segment with posterior margin produced from lateral angles to a bluntly angled apex.

Described from 14 female specimens labeled "Cala." in the C. F. Baker collection in the United States National Museum. Known only by female specimens.

Holotype female and female paratypes in the United States National Museum collection.

EMPOASCA FILAMENTA N. SP.

(Fig. 9)

Resembling *abrupta* and *arida* in size, form, and color, but distinguished by the different internal genital characters. Length 3.2 to 3.75 mm.

Vertex more than one-half longer on middle than next the eye, produced about one-half its length beyond the anterior margins of the eyes, more than a half wider between eyes than length at middle.

Color: Green varying in intensity, tints, and markings, frequently washed with yellow; vertex usually with the median stripe and oblique dashes, one either side just above the margin and again at base, white; pronotum usually with the three white spots on the anterior margin; scutellum with the broad white longitudinal stripe; elytra subhyaline.

Female genitalia: Last ventral segment twice as long as preceding segment, posterior margin strongly roundedly produced.

Male genitalia: Valve rather long, posterior margin concavely rounded; plates as broad as valve at base, gradually tapering to long attenuated tips which are frequently upturned. Of the male genital pieces, the lateral processes of the pygofers are long and slender, tapered to elongated and attenuated tips; the spines of the tenth segment are long, broad at base, rather broadly curved forward and extending about two-thirds the distance to the base of the pygofers.

Described from a series of three female specimens collected in Oregon September 7, and 6 males, 2 from the same locality and of the same date, 2 from Hood River, Oreg. (Webster No. 5914), collected by J. A. Hyslop, and 2 from Friday Harbor, Wash., collected from herbs in the Conifer Forest, July 26, 1928, by Martha Shackleford.

Holotype male, allotype female, and male and female paratypes in author's collection. Paratype males at Hood River, Oreg. (Webster No. 5914).

EMPOASCA FILAMENTA VAR. ABBREVIATA N. VAR.

(Fig. 9)

Size and coloration similar to those of *filamenta* and differing only in genital characters. Length 3.5 mm.

Male genital pieces: The chief difference between this and *filamenta* is in the shorter lateral processes of the pygofers, which seem to be proportionately wider. This may be only a variation in this character; yet it may be distinct from the preceding. Until more knowledge of these forms is obtained, it should probably be placed as a variety only. The styles are similar in these two forms, and the dorsal spine of the tenth segment is alike in both cases.

Collected at Hood River, Oreg., September 7. A series of seven specimens is at hand.

Holotype male, allotype female, and paratypes in author's collection.

EMPOASCA VINCULA N. SP.

(Fig. 10)

A banded species resembling *birdii* superficially, but with distinct genitalia. Length 3.75 mm.

Vertex bluntly angled, produced more than one-half its length beyond the anterior margins of the eyes, one-third longer on middle than next the eyes, more than one-half wider between eyes than length at middle; pronotum twice as long as vertex.

Color: Green; vertex, pronotum, and scutellum tinged with yellow and brown; elytra greenish, base of clavus, an elongated spot on center, claval suture, and the apical fourth of the elytra brown, veins and cross veins pale. These mottled areas give the elytra a banded appearance.

Female genitalia: Last ventral segment with posterior margin almost truncate, slightly produced at middle.

Male genitalia: Valve about twice as long as preceding segment, truncated posteriorly; plates large, parallel margined for about half their length, then tapered to acute tips. Of the male genital pieces, the lateral processes of the pygofers are long, with blunt, divergent apices, not narrowed or tapered; spines

of tenth segment heavy at base, sloping forward, narrowed and hooked backward and strongly inward into the genital chamber. It is unique in this respect and differs from any other species of the genus.

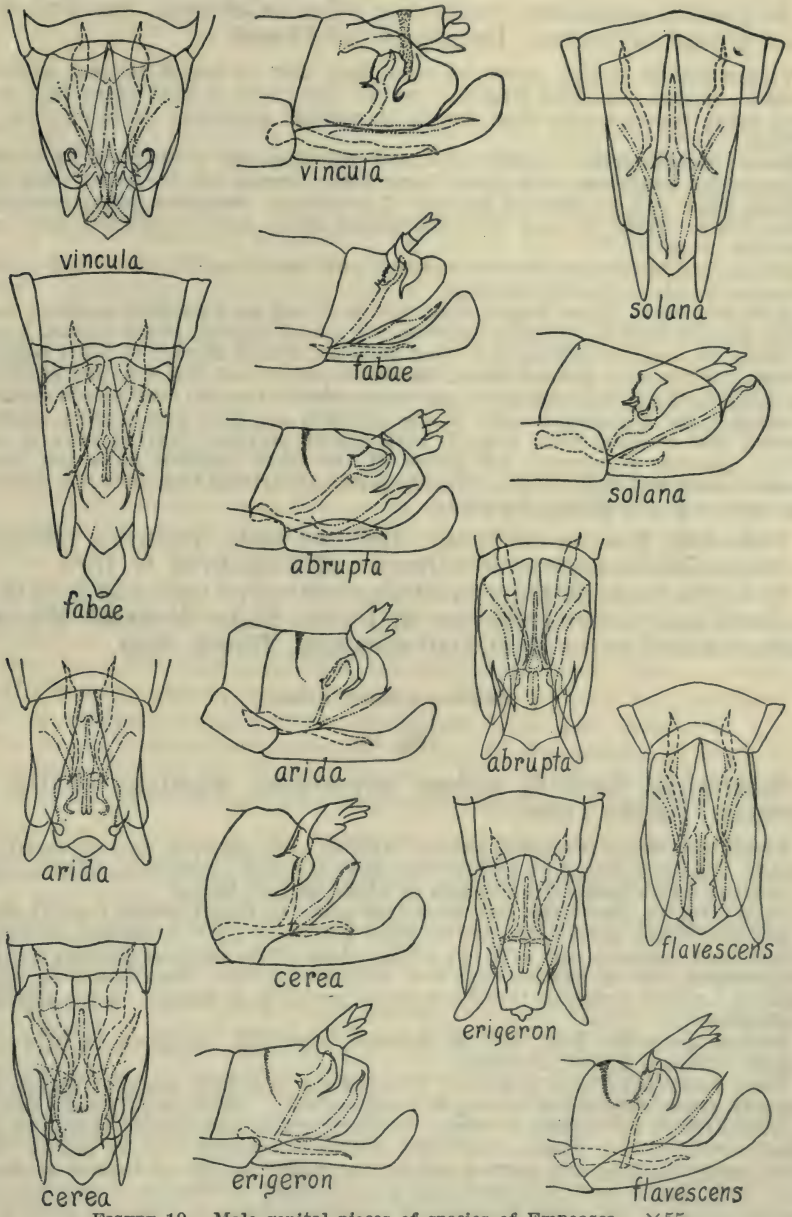

FIGURE 10.—Male genital pieces of species of Empoasca. ×55

Described from three female and two male specimens collected at Birtle, Manitoba, from May 26 to August 8, 1928, by R. D. Bird.

Holotype male, allotype female, and male and female paratypes in author's collection. Paratype female in United States National Museum collection.

EMPOASCA DELUDA N. SP.

(Fig. 9)

In general appearance resembling *fabae* or *abrupta*, but with distinct genital characters. Length 3.5 to 3.75 mm.

Vertex bluntly angled, produced more than half its length beyond anterior margins of eyes, one-third longer on middle than next to eyes, more than one-half wider between eyes than length at middle; pronotum twice as long as vertex.

Color: Bright green; vertex with pale markings on median line and disk either side; pronotum with three large white areas, one at middle and one behind either eye on anterior portion of pronotum; scutellum with the apical third white; elytra greenish with subhyaline white spots, sometimes only pale greenish areas.

Female genitalia: Last ventral segment with margin on posterior half rather strongly, evenly, convexly rounded.

Male genitalia: Valve longer than and as broad as preceding segment, posterior margin slightly concaved between the lateral angles; plates robust, broad at base, two and one-half times as long as broad, evenly sloping to blunt pointed apices. Of the male genital pieces, the styles are curved and enlarged at about the middle, the apical half more narrowed, almost straight, the apices slightly divergent; the lateral processes of the pygofers are long and slender, sloping inward and crossing near middle, with apical portions curving inward and almost meeting at center; the spines of the tenth segment have the basal portion broad and heavy and a spinelike structure arising from this and extending anteriorly and slightly ventrally.

Described from seven female and two male specimens collected at Birtle, Manitoba, May 26 to August 27, 1928, by R. D. Bird.

Holotype male, allotype female, and paratype male and female in author's collection. Paratypes in United States National Museum collection and in the E. D. Ball collection, Tucson, Ariz.

EMPOASCA CEREA N. SP.

(Fig. 10)

Resembling *fabae* in general appearance, markings similar to *abrupta*. Length 3 mm.

Vertex roundedly produced, almost twice as wide between eyes as length at middle, one-third longer on middle than next the eyes; pronotum twice as long as vertex; elytra exceeding abdomen by about half its length.

Color: Vertex, pronotum, and scutellum green to bright yellow; vertex with a pair of oblique spots near eyes on basal portion, a pair on margin, one each side of apex, and one next each eye white; three white spots on anterior margin of pronotum, one at middle, and one behind each eye; scutellum with spots forming a rather irregular transverse band just back of middle; elytra greenish subhyaline.

Female genitalia: Last ventral segment roundedly produced on posterior margin, obtusely angled at middle.

Male genitalia: Valve concavely rounded on posterior margin; plates triangular, about three times as long as width at base. Of the male genital pieces, in ventral view the lateral processes of the pygofers are parallel margined for about one-third their length, then taper to long attenuated tips; in lateral view these processes have long narrow apices; the styles are curved inward at about half their length and are narrowed with the apices slightly diverging; the dorsal spines of the tenth segment are roundedly inflated from the base, then narrowed and produced into a terminal process which is curved ventrally and anteriorly.

Described from a series of 50 specimens, both sexes, in the collection of E. D. Ball. These were collected at Monroe, Helper, and Soldier, Utah, July and August, 1906, and from Hamilton County, Calif., by E. G. Titus from sugar beets August 21, 1907.

Holotype male, allotype female, and paratypes in collection of E. D. Ball. Paratypes in the United States National Museum collection and in the author's collection.

EMPOASCA FABAE HARRIS

(Fig. 10)

Because of its economic importance and the great variability in color and color patterns this species is known in literature under a variety of names. As far as can be ascertained it was first described by Harris in 1841 (*16, p. 186*) under the genus Tettigonia. In 1853 (*19*) it was redescribed as *mali* by Le Baron as a member of Tettigonia. Again in 1864 (*27*), when Walsh erected the genus Empoasca, it was apparently redescribed under three different names where color variations were encountered. The types were destroyed in the Chicago fire, and his species can not be verified, and the original descriptions do not distinguish them specifically. In his paper Walsh redescribed it as *viridescens*, *consobrina*, and *malefica*, the last named under the genus Chloroneura. In 1884 (*12*) Forbes redescribed it as *albopicta* in the genus Empoa.

Again in 1898 Gillette (*13*) redescribed it in part as *pallida* from a series of specimens taken from cotton and placed in alcohol which had caused the green color to entirely disappear, leaving pure white insects. Also in the same paper he referred certain of these color forms to *flavescens*, a European species which does not occur in North America so far as can be determined from material examined. Therefore, a large number of American references by Gillette and workers who followed him have actually dealt with *fabae* or with one of the other closely related species. These records will probably never be correctly placed unless specimens have been retained.

The most common and variable species in the genus, at least in the eastern part of the United States. Pale green, usually with a row of white spots on anterior margin of pronotum. Length 3.5 mm.

Vertex bluntly angled, a little longer on middle than next eye and about one-third wider between eyes than length at middle.

Color: Yellowish to pale green, markings variable; vertex frequently with pale or dark green spots; pronotum usually with a row of six or more pale spots along anterior margin which are sometimes missing or indistinct; elytra greenish subhyaline.

Female genitalia: Last ventral segment moderately produced and roundedly truncated.

Male genitalia: Valve produced and rounded or bluntly angled; plates triangularly tapered to pointed apices which are frequently upturned. Of the male genital pieces, the lateral processes of the pygofers are rounded on inner margins and broadened on apical half, then concavely rounded to narrow attenuated tips which are slightly curved inward; the spines of the tenth segment are broad with tips narrowed and directed downward. This combination of characters will distinguish it from the closely related species.

Specimens in the United States National Museum are from Pennsylvania (on apple), Virginia, Michigan, Chicago and Algonquin, Ill., Alabama, Massachusetts, Arkansas (on apple), Louisiana (potato and apple), District of Columbia, Florida, Kansas, Maryland, Iowa, New York, Missouri, Nebraska, and North Carolina (on cotton, described as *pallida* by Gillette).

This is probably the most injurious species of the genus. It is known to occur on a great variety of plants. It is common on potato,

bean, clover, alfalfa, eggplant, rhubarb, cotton, dahlia, and to a large extent upon apple, especially the younger trees or nursery stock. These are probably the most important food plants, although it has been recorded from many others.

Life-history studies (*4*) have revealed four distinct broods of these leaf hoppers during the season, with one complete generation, a second almost complete, a partial third, and a smaller partial fourth generation. Under field conditions in Ohio in 1927 the first eggs were laid about May 25, and on November 1 eggs were still hatching.

EMPOASCA ABRUPTA N. SP.

(Figs. 2 and 10)

Resembling *fabae* in size, form, and appearance but usually with different markings. The internal genitalia are distinct. Found only in the West and Southwest. Length 3.5 mm.

Vertex produced almost one-half its length before the anterior margins of the eyes, about one-third longer on middle than next the eyes and one-half wider between eyes than length at middle; elytra long.

Color: Green marked with white; vertex with a median stripe, a pair of oblique dashes just above ocelli, and a pair on the base white; pronotum usually with three large white spots on anterior margin; a broad white stripe across middle of scutellum; elytra greenish, subhyaline, nervures green.

Female genitalia: Last ventral segment strongly roundedly produced, more than twice the length of the preceding segment.

Male genitalia: Valve a little longer than last ventral segment, posterior margin concavely rounded; plates rather broad at base, long and tapered to pointed apices. Of the male genital pieces, the lateral processes of the pygofers in ventral view are rather broad and almost parallel margined to near apex where they are abruptly narrowed to form slender, fingerlike processes on their outer margins; the spines of the tenth segment are rather long, tapering, directed downward and then forward at the apex.

A large number of this species were collected on potato and forwarded from California by H. H. P. Severin. The injuries to potato and bean are entirely different from the injury produced by *fabae* upon the same plants. It should probably be given the common name, "western potato leaf hopper."

This species, together with *arida*, replaces *fabae* as a truck-crop pest in the extreme western part of the United States.

Described from a series of 17 specimens collected at Stockton, Calif., August, 1919, by F. E. Blaisdell, a series collected from potato by H. H. P. Severin near Berkeley, Calif., May, 1929, and a series of specimens in the United States National Museum from California, Colorado, Arizona, Texas, and Oregon.

Holotype male, allotype female, and paratypes in author's collection. Paratypes in the United States National Museum collection, in Canadian National collection, and in the collection of E. D. Ball.

EMPOASCA ERIGERON N. SP.

(Fig. 10)

A small green species resembling *fabae* but with more produced head. Length 3 mm.

Vertex bluntly produced about one-half its length beyond the anterior margins of the eyes, more than one-half as long on middle as next the eyes, and about one-half wider between eyes than length at middle; pronotum one-half longer than vertex.

Color: Green, tinged with yellow, markings variable; vertex usually with a median stripe and a pale, curved, parenthesis mark at either side on disk and extending the length of the vertex; pronotum with three large white spots on anterior margin, one at middle, and one behind each eye; elytra yellowish brown, apical portion white, veins conspicuous.

Female genitalia: Last ventral segment with posterior margin roundedly produced.

Male genitalia: Valve slightly indented on posterior margin; plates about three times as long as width at base, tips upturned one-third their length with apices bluntly angled. Of the male genital pieces, the lateral processes of the pygofers are long and almost parallel margined with fingerlike processes on outer margins in ventral view, in lateral view with a narrowed, curved, fingerlike portion at apex; spines of tenth segment broad at base, directed ventrally and with apical portion curved sharply and directed almost anteriorly.

Described from a series of 42 specimens taken by the author at Covington, Dyersburg, and Clarksville, Tenn., in June, July, and August of 1915 and 1917.

Since describing this species from material collected about 12 years ago, a large number of specimens have been examined from Washington, D. C. (Poos), and Columbus, Ohio (DeLong). Doctor Poos has found in connection with his work with *fabae* that the species *erigeron* passes the winter in the egg stage upon *Erigeron annuus* and several other wild hosts. In Ohio it hatches in these habitats in late April and early May and is one of the earliest of the genus flying in the spring. Because of this it has undoubtedly been mistaken for *fabae* upon wild host plants in early spring by previous workers, especially since it is so common and abundant.

Holotype male, allotype female, and paratypes in author's collection. Paratypes in the United States National Museum collection and in the collection of E. D. Ball.

EMPOASCA ARIDA N. SP.

(Fig. 10)

Resembling *fabae* in form and appearance and definitely distinguished from it only by an examination of the internal male genitalia. It occurs only in the western part of the United States according to present records. Length 3.2 to 3.5 mm.

Vertex bluntly produced about half its length before the anterior margins of the eyes, more than one-half longer on middle than next the eyes, one-half wider than length at middle; pronotum twice as long as vertex, humeral angles produced and prominent.

Color: Green, vertex and pronotum often tinged with yellow, markings variable; sometimes with three rather large white spots on anterior margin of pronotum or a series of about six smaller spots; scutellum usually with a median pale stripe sometimes almost concealed by the pronotum; elytra greenish subhyaline, abdomen usually visible from above.

Female genitalia: Last ventral segment with posterior margin roundedly produced.

Male genitalia: Valve twice as long as preceding segment, posterior margin roundedly produced; plates rather broad at base, two and one-half times as long as wide, tips upturned, plates frequently separated at tips, exposing upturned apices. Of the male genital pieces, the lateral processes of the pygofers in ventral view are almost parallel margined to near apex where they are narrowed, and formed into a hooked curved portion extending from the outer margins and with the apex extending inward; the spines of the tenth segment are long, tapering, broadly curved, with apices extending ventrally.

Described from a large series of more than 250 specimens in the collection of E. D. Ball, taken chiefly from sugar beets and alfalfa

in Utah and California. Localities represented by this material are Oxnard, Chino, Stanford University, Salinas, Riverside, Pasadena, Spreckles, and Sacramento, Calif., and Logan and Soldier, Utah.

In the western part of the United States this species apparently partially replaces or is comparable to *fabae* in the East, especially upon such plants as the sugar beet.

Holotype male, allotype female, and paratypes in the E. D. Ball collection. Paratypes in the United States National Museum collection and in that of the author.

EMPOASCA SOLANA N. SP.

(Fig. 10)

In size and appearance resembling *fabae*, but bright green without markings on vertex or pronotum and with distinct internal genitalia. Length 3.3 mm.

Vertex bluntly produced, about one-third longer on middle than next the eyes, almost one-half wider between eyes than length at middle, produced about one-half its length beyond anterior margins of the eyes; pronotum about one-half longer than vertex.

Color: Bright green, washed with yellow; vertex and pronotum strongly tinged with golden yellow; scutellum with a median white stripe and some white spots on posterior half; elytra greenish subhyaline tinged with yellow.

Male genitalia: Valve three times as long as preceding segment, posterior margin slightly produced and rounded; plates triangular, elongate, rather broad at base, three times as long as basal width, gradually tapered to long acute tips. Of the male genital pieces the styles are almost parallel margined on the basal two-thirds and slope inward, then are narrowed and curved outward from outer margins; the lateral processes of the pygofers in ventral view appear abruptly narrowed and slightly attenuated at apex, in lateral view they are long and narrow, terminally narrowed, concavely curved upward forming a slightly hooked, narrowed apex; the spines of the tenth segment appear as rather broad chitinous plates with apices narrowed and bluntly rounded and directed anteriorly and ventrally.

Described from two male specimens collected on potato at Baton Rouge, La., one by T. H. Cutrer, October 28, 1918, and the other May 16, 1922, by C. E. Smith.

Holotype male, collected May 16, 1922, in the United States National Museum collection. Paratype male, collected October 28, 1918, in the author's collection.

THE SUBGENUS IDONA NOV.

Vertex strongly produced, sometimes bluntly, but usually distinctly angled. In all species the vertex is almost as long at middle as width between the eyes. In some cases the vertex is longer on middle than the width.

Type of subgenus, *minuenda* Ball.

KEY TO SPECIES OF THE SUBGENUS IDONA NOV.

A. Length more than 3 mm.
  B. Length 4 mm ..... *panda*, p. 51
 BB. Less than 4 mm. in length.
   C. Dark green washed with brown, without definite markings; vertex yellowish green; occurs on red cedar ..... *junipera*, p. 51
  CC. Paler greenish or yellow with distinct color markings.
    D. Long and narrow, pale yellowish green, unmarked; male lateral processes of pygofers very short and tapered. (Fig. 11) ..... *elongata*, p. 53

DD. More robust, shorter, not over 3.5 mm.; reddish brown, or with red markings; male lateral processes of pygofers long and with distinct apical structures.
E. White to pale green, vertex mottled with bright red leaving white areoles; male lateral processes of pygofers long and bowed ---------- *rufa*, p. 53
EE. With dull red or brownish red coloration and without white areoles on vertex.
F. Yellowish tinged with red; pronotum and scutellum dull reddish; male lateral processes of pygofers with inwardly curved tips ---------- *tincta*, p. 54
FF. Elytra pale green with brownish markings, a large pale area on base of clavus at either side; male lateral processes of pygofers with fingerlike tips, projecting on outer apical margins *morrisoni*, p. 54

AA. Length less than 3 mm.
G. Very small, not exceeding 2 mm. in length, common on avocado in Florida ---- *minuenda*, p. 55
GG. Larger, 2.5 mm. or more.
H. Vertex strongly angled, almost as long at middle as width between eyes; elytra pale green, a reddish or orange stripe along claval suture ---------- *radiata*, p. 56
HH. Vertex more bluntly angled, about one-half wider between eyes than length at middle; elytra greenish, veins white.
---------- *mexicana*, p. 56

SPECIES OF THE SUBGENUS IDONA NOV.

EMPOASCA PANDA N. SP.

(Fig. 11)

A rather large species with strongly produced vertex, yellowish, marked with white. Length 4 mm.

Vertex produced more than half its length beyond anterior margins of eyes, almost twice as long on middle as next the eyes, about two-thirds wider between eyes than length at middle; pronotum more than twice as long as vertex; humeral angles produced and prominent.

Color: Golden yellow, elytra pale green; vertex with median white stripe, a pair of oblique dashes just above margin and a pair on basal portion white; three white spots on anterior margin of pronotum; scutellum with a broad median white stripe.

Female genitalia: Last ventral segment roundedly produced.

Male genitalia: Valve broad, slightly concave; plates rather long, gradually tapered to acutely angled tips. Of the male genital pieces, in ventral view the lateral processes taper to pointed apices, in lateral view they are convexly bowed outward just before the apex; the styles are rather short and in ventral view are roundedly inflated at the base, the apices taper and are divergent; the dorsal spines are heavy at the base, and a terminal spur projects at right angles from the basal portion.

Described from two female and two male specimens from Vancouver, B. C., in the C. F. Baker collection, labeled 2228.

Holotype male, allotype female, and paratypes in the United States National Museum collection.

EMPOASCA JUNIPERA N. SP.

A dark green species which occurs on red cedar and has the most pointed head of any of the species of the genus. Length 3.3 mm.

Vertex produced more than one-half its length before the anterior margins of the eyes, almost twice as long on middle as next the eyes, one-half wider between eyes than middle length; pronotum less than one-half longer than vertex.

Color: Dark green tinted with brown; vertex yellow-green, a bright green area above apex; pronotum with a pale area behind either eye; elytra brownish green, unmarked, apices smoky; face and beneath yellowish to green.

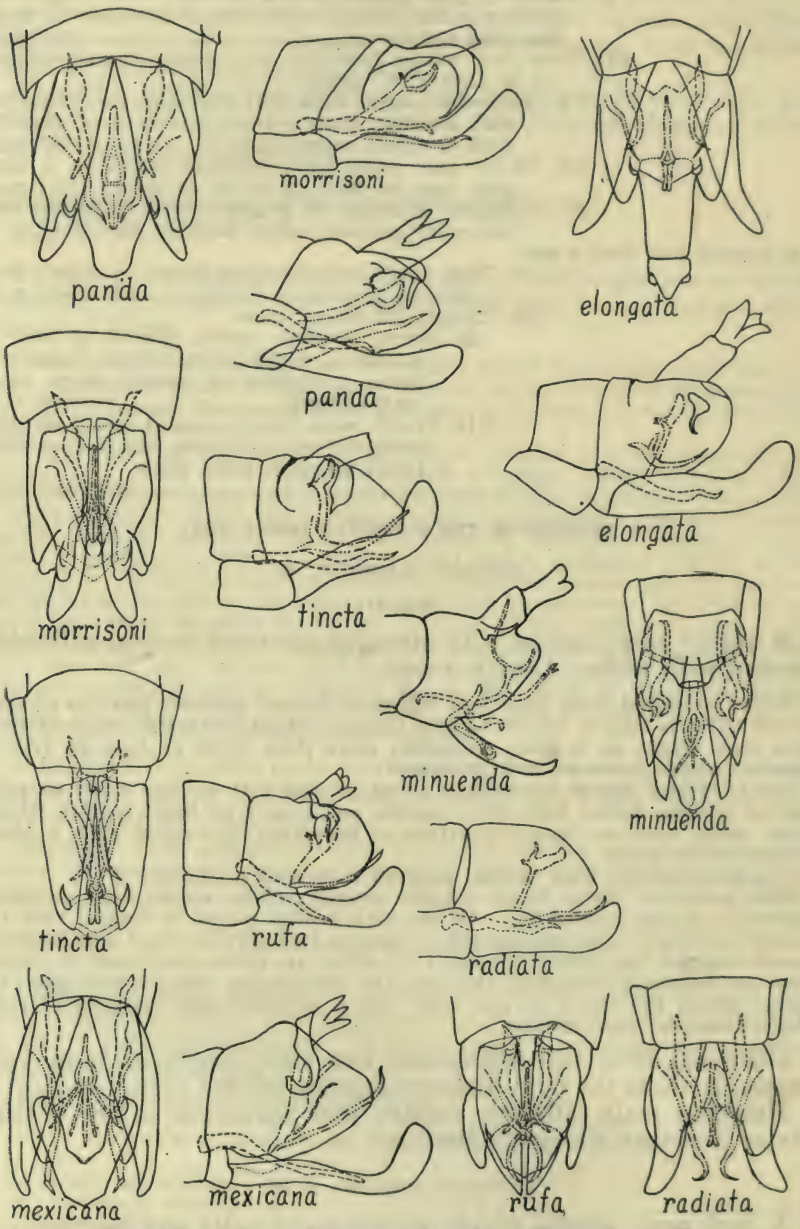

FIGURE 11.—Male genital pieces of species of Empoasca. ×55.

Female genitalia: Last ventral segment more than twice as long as preceding, posterior margin appearing almost truncate, slightly indented on either side of central slightly produced lobe or tooth.

Male genitalia: Valve slightly produced, plates appearing short, rather narrow, and with upturned tips.

Described from a series of one male and six female specimens collected from red cedar, *Juniperus virginiana*, at Newport, Tenn., June 14, 1928, by Neale F. Howard and the author. The female is designated as the type; although the male is apparently of the same species, it has a slightly shorter vertex.

Holotype female, allotype male, and paratypes in the author's collection. Paratype female in the United States National Museum collection.

EMPOASCA ELONGATA N. SP.

(Fig. 11)

A long, slender species, pale green to yellow, with a rather strongly produced head and with distinct genital characters. Length 3.75 mm.

Vertex produced about two-thirds its length beyond anterior margins of the eyes, almost twice as long on middle as next the eyes, about one-half wider between eyes than length at middle; elytra very long and narrow.

Color: Green to yellowish, pronotum and scutellum sometimes tinged with orange-yellow; vertex usually with a median stripe and pronotum usually with three spots on the anterior margin and a white stripe on scutellum; elytra pale green, an orange stripe extending from base of wing just outside the claval suture almost to cross veins, also an orange stripe on inner margins of elytra along commissural line from scutellum to apex of clavus.

Female genitalia: Last ventral segment with posterior margin rather gently, broadly curved and only slightly produced.

Male genitalia: Valve narrowed, posterior margin slightly produced; plates rather small, narrow, and appearing rather short, about two and one-half times as long as broad at base, tips rather strongly upturned, plates densely covered with fine white hairs. Of the male genital pieces, the styles are narrow, quite strongly curved outward on apical half; the lateral processes of the pygofers are rather short, curved at base, then tapering to acutely pointed tips; the spines of the tenth segment are narrowed apically and directed ventrally and posteriorly.

Described from a series of 16 females and 7 males collected at Friday Harbor, San Juan Island, Wash., July 26, 1928, by Martha Schakleford, from shrubs in coniferous and alder forests. Also from a series of 12 specimens in E. D. Ball's collection from Sacramento, and Spreckles, Calif., and Helper, Utah, collected in August and September, 1906 and 1907.

Holotype male and allotype female, and paratypes in the author's collection. Paratypes in the collection of E. D. Ball and in the United States National Museum collection.

EMPOASCA RUFA, N. SP.

(Fig. 11)

A small white species with reddish mottling on the head and with distinct genital characters. Length 3.2 mm.

Vertex bluntly pointed, produced about one-half its length beyond anterior margins of the eyes, almost twice as long on middle as next eyes, about one-fourth broader between eyes than length at middle; pronotum one-half longer than vertex.

Color: White, upper portion of face, margin of vertex between eyes, and vertex with a complete network of bright red pigmentation with round white spots exposed. On the vertex there is a large white spot just above apex which is constricted behind, then expanded to form a large basal spot; a pair of spots either side between this basal spot and the eye and a pair on each side of apex on the margin; the outer spot on each side envelopes the ocellus.

Pronotum milk white flecked with gray; elytra milky white flecked with small round gray spots, a larger one about the middle of the clavus along the commissural line of each elytron, apex faintly smoky, nervures white.

Female genitalia: Last ventral segment slightly concavely rounded from prominent lateral angles.

Male genitalia: Valve produced, posterior margin concave; plates appearing twice as long as valve and pointed, but with tips upturned and blunt or rounded. Of the male genital pieces, the styles are strongly curved outward at middle with tips strongly diverging; the oedagus is narrow at base, enlarged at apex; the lateral processes of the pygofers are long and curving, in ventral view directed inward, and crossing just beyond middle, then with apices produced and curved inward until they almost touch; the spines of the tenth segment are short and broad, directed backward, then downward, with apices acutely pointed.

Described from a series of one female and seven male specimens collected at Pasadena, Calif., June 17, 1908, by E. D. Ball. The male is designated as the type.

Holotype male, allotype female, and paratypes in the E. D. Ball collection. Paratype male in the author's collection.

EMPOASCA TINCTA N. SP.

(Fig. 11)

Easily distinguished from the other members of the genus by its pointed head and dull reddish tint. Length 3.5 mm.

Vertex decidedly pointed or angled and produced more than half its length before the anterior margins of the eyes, almost twice as long at middle as next the eyes, about one-half wider between the eyes than length at middle.

Color: Vertex yellowish, sometimes tinged with red; pronotum and scutellum dull reddish; elytra slightly tinged, subhyaline; abdomen reddish, and easily visible from above; beneath, yellow tinged with red.

Female genitalia: Last ventral segment with posterior margin roundedly produced, the entire margin shallowly notched so as to form about six short, rounded lobes.

Male genitalia: Valve rather broad, truncated posteriorly, and slightly notched at middle; plates rather broad at base, produced and appearing blunt at the tips, but with apical portion turned upward. Of the male genital pieces, the styles are long and slender, curved inward just beyond the center, their apices diverging; the lateral processes of the pygofers are slender, curved outward just before the apex, their tips converging; the spines of the tenth segment are broad and appear more like plates with apices narrowed and pointed and directed ventrally.

Described from a series of six female and five male specimens from Ephraim, Utah, July 20, 1914, in the collection of E. D. Ball.

Holotype male, allotype female, and paratypes in the E. D. Ball collection. Paratypes in the author's collection and in the United States National Museum collection.

EMPOASCA MORRISONI HARTZELL

(Fig. 11)

Described by Hartzell in 1923 (*18*).

A species with prominently produced head and distinct white markings. Internal genital characters distinct. Length 3.5 mm.

Vertex prominently produced and sharply rounded, almost twice as long at middle as next the eye, one-half wider between the eyes than length at middle, produced more than one-half its length before anterior margins of the eyes, pronotum long, about twice as long as vertex.

Color: Vertex, pronotum, and scutellum pale brown; vertex with a median white line and a spot on either side just above apex; pronotum with three large white spots, one at middle and one behind either eye along anterior margin; elytra pale green marked with brown and white, anterior third washed with brown, a large pale green area almost white on the base of the clavus, apical third of elytra brown or smoky, veins broadly greenish and prominent.

Female genitalia: Last ventral segment roundedly produced to rather prominently angled apex.

Male genitalia: Plates about four times as long as basal width, tips upturned. Of the male genital pieces, the styles are enlarged at the center and produced almost straight, sloping inwardly to apices; the lateral processes of the pygofers are long, almost parallel margined and with slender produced fingerlike processes on the outer margins as seen in ventral view; the spines of the tenth segment are long, broad at base, then gradually narrowed to acute apices which are directed ventrally and slightly anteriorly.

This species is known only from a series of specimens collected by Harold Morrison in a pine grove at Pacific Grove, Calif., May 29, 1915.

Type in the Morrison collection, United States National Museum.

EMPOASCA MINUENDA BALL

(Fig. 11)

Described by Ball in 1921 (*1*).

A very small, green species with strongly angled vertex. It is a pest of avocado. Length 2 mm.

Vertex sharply angled, produced about one-half its length before the anterior margins of the eyes, twice as long on middle as next eyes and as long at middle as width between the eyes; pronotum one-half longer than vertex.

Color: Varying from pale to golden yellow, without definite markings except in varietal forms.

Female genitalia: Last ventral segment with the posterior margin roundedly produced.

Male genitalia: Valve triangularly produced; plates elongate, triangular, narrowed to attenuate apices which are upturned. The structures of the male genital pieces are very peculiar in *minuenda* and rather difficult to describe. In ventral view a pair of processes arise at about the middle of the oedagus and extend caudally and posteriorly. The oedagus extends dorsally from this point and another portion curves off in the same manner, but is not paired. The lateral processes of the pygofers seem to be lacking or so minute that they are not easily recognized. The styles are long and narrow at the base, then become enlarged and divergent with a convexly curved fingerlike process arising on the inner margin of each near its apex.

Described from specimens collected at Miami, Fla., on avocado by G. F. Moznette and known only from this place and food plant.

This species resembles very strongly a Dikraneura in general appearance, and the wing venation is slightly different from the typical Empoasca venation, but according to the present classification it should probably be placed in the *radiata* group.

Type in collection of E. D. Ball.

EMPOASCA MINUENDA VAR. MOZNETTEI BALL

Described by Ball as variety *moznettei* in 1921 (*1*).

Differing from typical *minuenda* by a pair of separated spots on the pronotum, three spots, one large and two small, on the scutellum, and six spots on each elytron black. Two are found on the clavus, three on the costa, and one on the corium of the elytra.

Found on avocado with typical *minuenda*.

EMPOASCA MINUENDA VAR. CLAVIGERANA BALL

Described by Ball as variety *clavigerana* in 1921 (*1*).

Differing from typical *minuenda* by a pair of dark stripes which arise just back of margin of vertex and extend across vertex, pronotum, and scutellum, and along inner margins of elytra where they frequently appear as one stripe, fusing on the scutellum. These stripes are sometimes composed only of broken dashes.

Occurs on avocado in company with the preceding species and variety.

EMPOASCA RADIATA GILLETTE

(Figs. 2 and 11)

Described by Gillette in 1898 (*13*).

A small species with strongly produced vertex and with reddish or orange stripes on clavus of elytra. Length 2.75 mm.

Vertex produced more than one-half its length beyond the anterior margins of the eyes, twice as long on middle as next to eyes and only slightly wider between eyes than length at middle; pronotum about one-third longer than vertex, humeral angles prominent so that pronotum is wider than head.

Color: Dull greenish, marked with white and red; vertex with a paler median line and oblique dashes which are sometimes wanting; pronotum with three rather large white spots on anterior margin; scutellum with posterior half white; elytra pale greenish, a stripe along claval suture, a broad one along anal margin, and a stripe along anterior half of commissural line red or orange.

Female genitalia: Last ventral segment produced, posterior margin roundedly notched either side of produced central half.

Male genitalia: Valve about twice as long as preceding segment, posterior margin concavely rounded; plates rather long but appearing short and with pointed apices because of the lateral curling of the apical fourth. Of the male genital pieces, the styles are strongly curved at middle with tips divergent; the lateral processes of the pygofers are long with apices curved outward.

The type is from Colorado and other specimens in the National Museum collection are from Texas. Specimens in the author's collection are from Washington, D. C., and Knoxville, Clarksville, and Paris, Tenn.

This species was collected from herbaceous vegetation. The exact food plant is not known.

Type in the United States National Museum.

EMPOASCA MEXICANA GILLETTE

(Fig. 11)

Described by Gillette in 1898 (*13*).

A very small species with bluntly pointed head and a striped appearance. Internal male structures unique. Length 2.5 mm.

Vertex bluntly angled, produced more than one-half its length before anterior margins of the eyes, almost twice as long on middle as next the eyes, about one-half wider between eyes than median length; pronotum one-half longer than vertex.

Color: Green washed with yellow, vertex and pronotum varying from green to golden yellow; vertex with a median pale stripe sometimes extending across pronotum, a spot either side on margin, and a spot on either side at base white; scutellum with white mottling; elytra greenish subhyaline, the veins broadly white, causing the insect to appear striped.

Female genitalia: Last ventral segment broad, almost truncate.

Male genitalia: Valve concave and slightly broadly notched at center; plates robust, rather heavy, elongate, tips upturned and blunt, outer margins convexly

rounded, sparsely clothed with short, inconspicuous hairs. Of the male genital pieces, the styles are long and narrow, wider on basal than on apical half; the lateral processes are long and in lateral view curved upward at the tip, in ventral view they are narrow on basal two-thirds, then widened, and the apices are sharp pointed and directed inward; the oedagus is rather large, with a pair of long, slender processes arising on the posterior side near the base and extending almost dorsally. Another process arises in similar location but more dorsally. The dorsal spines of the tenth segment extend ventrally and curve sharply anteriorly. The apices of these processes are broad and heavy.

A series of specimens consisting of five females and three males collected at Marfa, Tex., June 5, 1908, by Mitchell and Cushman, and now in the United States National Museum collection, are apparently this species. Gillette's type could not be located in the National Museum.

LIST OF DESCRIBED SPECIES WITH SYNONYMS

In the present revision 51 species have been treated. Twenty-four of these have been described before and 27 are described as new in this bulletin. In addition to those mentioned above, 13 species are placed as synonyms of other described species, and 1 European species is placed as a synonym of an American species because it was cited in error. Also 10 varieties are treated, 7 of which were previously described and 3 of which are described as new in this revision.

The species and varieties have been placed in four subgenera, two of which were previously described and two of which are described in this bulletin. A list of the species and varieties treated in this revision follows:

Subgenus Kybos Fieber:
- *pergandei* Gillette (1898).
- *acodens* n. sp.
- *pectinata* n. sp.
- *trilobata* n. sp.
- *maligna* Walsh (1864).
  - unicolor Gillette (1898).
  - denticula Gillette (1898).
- *atrolabes* Gillette (1898).
- *unica* Provancher (1890).
  - splendida Gillette (1898).
- *obtusa* Walsh (1864).
  - incisa Gillette (1898).
- *incida* n. sp.
- *patula* n. sp.
- *patula* var. *magna* n. var.
- *albolinea* Gillette (1898).
- *saluta* n. sp.
- *aureoviridis* Uhler (1877).
- *aureoviridis* var. *vittata* Hartzell (1923).
- *smaragdula* Fallen (1806).
  - viridipes Curtis (1837).
- *trifasciata* Gillette (1898).
- *digita* n. sp.
- *copula* n. sp.
- *livingstoni* Gillette (1898).
- *clypeata* Gillette and Baker (1895).
- *clypeata* var. *annella* Hartzell (1923).
- *adunca* n. sp.
- *osborni* Hartzell (1923).

Subgenus Hebata nov.:
- *nigra* Gillette and Baker (1895).
- *nigra* var. *typhlocyboides* (1895).
  - robusta Gillette (1898).
- *nigra* var. *nigroscuta* Gillette and Baker (1895).
- *nigra* var. *pulchella* Gillette and Baker (1895).
- *aspersa* Gillette and Baker (1895).
- *alboneura* Gillette (1898).
  - tumida Gillette (1898).
- *coccinea* Fitch (1851).

Subgenus Empoasca Walsh:
- *recurvata* n. sp.
- *snowi* Gillette (1898).
- *rubida* n. sp.
- *barbara* Hartzell (1923).
- *bifurcata* n. sp.
- *birdii* Goding (1890).
  - pallida Gillette (1898) in part.
- *pallidula* n. sp.
- *hamata* n. sp.
- *hamata* var. *albonota* n. var.
- *filamenta* n. sp.
- *filamenta* var. *abbreviata* n. var.
- *vincula* n. sp.
- *deluda* n. sp.
- *cerea* n. sp.
- *fabae* Harris (1841).
  - mali LeBaron (1853).
  - viridescens Walsh (1864).
  - consobrina Walsh (1864).
  - malefica Walsh (1864).
  - albopicta Forbes (1884).
  - pallida Gillette (1898) in part.
  - flavescens Fabricius (1794) (American records cited in error).
- *abrupta* n. sp.
- *erigeron* n. sp.
- *arida* n. sp.
- *solana* n. sp.

Subgenus Idona nov.:
- *panda* n. sp.
- *junipera* n. sp.
- *elongata* n. sp.
- *rufa* n. sp.
- *tincta* n. sp.
- *morrisoni* Hartzell (1923).
- *minuenda* Ball (1921).
- *minuenda* var. *moznettei* Ball (1921).
- *minuenda* var. *clavigerana* Ball (1921).
- *radiata* Gillette (1898).
- *mexicana* Gillette (1898).

SPECIES NOT INCLUDED IN THIS REVISION

Empoasca tessellata (Fieber). Described by Fieber (*10*) in 1872 as *Chlorita tessellata*. Although specimens of this European species have not been examined, it is apparently different from Gillette and Baker's *aspersa* which had been cited as a synonym and if so it apparently does not occur in North America.

Empoasca salinarum (Berg). Described as *Typhlocyba salinarum* by Berg (*2, p. 274*) in 1879. It apparently does not occur in North America.

Empoasca flavescens (Fabricius). Described as *Cicada flavescens* by Fabricius (*6, p. 46*) in 1794. As stated previously in this paper, *flavescens* has not been found in any material available for examination at this time. A drawing has been included in Figure 8, however, to facilitate comparison with American species.

Empoasca pura (Stål). Described as *Typhlocyba pura* by Stål (*23, p. 195*) in 1858. No specimens authentically identified have been available for comparison, and from the description it seems doubtful that this species is represented in North America. It has therefore been omitted from this revision of the North American species.

Empoasca alboscripta Van Duzee. Described by Van Duzee (*25, p. 56*) as *Empoasca alboscripta* in 1914. This is undoubtedly a true Empoasca but it has been impossible to secure any material authentically identified. Since a number of species are closely related it has been impossible to place it, and it has therefore been omitted from the present revision.

LITERATURE CITED

(1) BALL, E. D.
1921. THE SMALLEST KNOWN LEAF HOPPER. Wash. Biol. Soc. Proc. 34: 23–24.

(2) BERG, C.
1879. HEMIPTERA ARGENTINA. 316 p. Bonariae.

(3) CURTIS, J.
1837. BRITISH ENTOMOLOGY; BEING ILLUSTRATIONS AND DESCRIPTIONS OF THE GENERA OF INSECTS FOUND IN GREAT BRITAIN AND IRELAND. v. 14, illus, London.

(4) DELONG, D. M.
1928. SOME OBSERVATIONS UPON THE BIOLOGY AND CONTROL OF THE POTATO LEAF HOPPER (EMPOASCA FABAE HARRIS). Jour. Econ. Ent. 21: 183–188, illus.

(5) DOUGLAS, J. W.
1875. NOTES ON BRITISH HOMOPTERA, WITH DESCRIPTIONS OF ADDITIONAL SPECIES. Ent. Mag. 11: 198–199; 12: 26–29, 76–79.

(6) FABRICIUS, J. C.
1792–94. ENTOMOLOGIA SYSTEMATICA EMENDATA ET AUCTA, SECUNDUM CLASSES, ORDINES, GENERA, SPECIES, ADJECTIS SYNONIMIS, LOCIS, OBSERVATIONIBUS, DESCRIPTIONIBUS. Hafniae.

(7) FALLÉN, C. F.
1806. FÖRSÖK TILL DE SVENSKA CICAD-ARTERNAS UPPSTÄLLNING OCH BESKRIFNING. K. Vetensk. Acad. Nya Handlingar. 27: 6–43, 113–129.

(8) ———
1826. HEMIPTERA SVECIA; CICADARIAE, FULGORIDES, TETTIGONIDES. 80 p. Londini.

(9) FIEBER, F. X.
1866. NEUE GATTUNGEN UND ARTEN IN HOMOPTERN (CICADINA BUR.). Verhandl. Zool.-Bot. Gesell. Wien 16: [497]–516, illus.

(10) FIEBER, F. X.
1872. KATALOG DER EUROPAISCHEN CICADINEN. 19 p. Wien.
(11) FITCH, A.
1851. CATALOGUE WITH REFERENCES AND DESCRIPTIONS OF THE INSECTS COLLECTED AND ARRANGED FOR THE STATE CABINET OF NATURAL HISTORY. N. Y. State Cabinet of Nat. Hist. Regents Univ. Ann. Rpt. 4: [5]–69.
(12) FORBES, S. A.
1884. INSECTS INJURIOUS TO THE APPLE. Ill. State Ent. Rpt. 13: 181–183, illus.
(13) GILLETTE, C. P.
1898. AMERICAN LEAF HOPPERS OF THE SUBFAMILY TYPHLOCYBINAE. U. S. Natl. Mus. Proc. 20: [709]–773, illus.
(14) ——— and BAKER, C. F.
1895. A PRELIMINARY LIST OF THE HEMIPTERA OF COLORADO. Colo. Agr. Expt. Sta. Bul. 31 (Tech. Ser. 1), 137 p., illus.
(15) GODING, F. W.
1890. A NEW APPLE PEST. Ent. News 1: 123–124.
(16) HARRIS, T. W.
1841. A REPORT ON THE INSECTS OF MASSACHUSETTS, INJURIOUS TO VEGETATION. 459 p. Cambridge.
(17) HARTZELL, A.
1921. FURTHER NOTES ON THE LIFE HISTORY OF THE POTATO LEAF HOPPER. (EMPOASCA MALI LE BARON.) Jour. Econ. Ent. 14: 62–68, illus.
(18) ———
1923. THE GENUS EMPOASCA IN NORTH AMERICA. Iowa Acad. Sci. Proc. 30: 87–127, illus.
(19) LE BARON, W.
1853. OBSERVATIONS UPON TWO SPECIES OF INSECTS INJURIOUS TO FRUIT TREES. Prairie Farmer 13: 330–331.
(20) NAUDE, T. J.
1929. A TAXONOMIC AND FAUNISTIC STUDY OF SOUTH AFRICAN LEAFHOPPERS OF THE FAMILY CICADELLIDAE. Abstract of thesis, 1923, (Ph. D.) Ohio State University. 22 p.
(21) PROVANCHER, L.
1883–1890. PETITE FAUNE ENTOMOLOGIQUE DU CANADA ET PARTICULIÈREMENT DE LA PROVINCE DE QUÉBEC. v. 2–3, illus. Quebec.
(22) SEVERIN, H. H. P.
1929. YELLOWS DISEASE OF CELERY, LETTUCE, AND OTHER PLANTS TRANSMITTED BY CICADULA SEXNOTATA (FALL.). Hilgardia 3: [543]–582, illus.
(23) STÅL, C.
1858. BEITRAG ZUR HEMIPTEREN-FAUNA SIBIRIENS UND DES RUSSISCHEN NORD-AMERIKA. Stettin Ent. Ztg. 19: 175–198, illus.
(24) UHLER, P. R.
1877. REPORT UPON THE INSECTS COLLECTED BY P. R. UHLER DURING THE EXPLORATIONS OF 1875, INCLUDING MONOGRAPHS OF THE FAMILIES CYDNIDÆ AND SALDÆ, AND THE HEMIPTERA COLLECTED BY A. S. PACKARD, JR., M. D. Extracted from U. S. Dept. Int., Geol. and Geogr. Survey Bul. v. 3 (2): [355]–475; (4): 765–801, illus.
(25) VAN DUZEE, E. P.
1914. A PRELIMINARY LIST OF THE HEMIPTERA OF SAN DIEGO COUNTY, CALIFORNIA. San Diego Soc. Nat. Hist. Trans. 2 (1): 1–57.
(26) ———
1917. CATALOGUE OF THE HEMIPTERA OF AMERICA NORTH OF MEXICO, EXCEPTING THE APHIDIDAE, COCCIDAE, AND ALEURODIDAE. Calif. Univ. Pubs. Ent. Tech. Bul., v. 2, 902 p.
(27) WALSH, B. D.
1865. ON CERTAIN REMARKABLE OR EXCEPTIONAL LARVÆ, COLEOPTEROUS, LEPIDOPTEROUS, AND DIPTEROUS, WITH DESCRIPTIONS OF SEVERAL NEW GENERA AND SPECIES, AND OF SEVERAL SPECIES INJURIOUS TO VEGETATION, WHICH HAVE ALREADY BEEN PUBLISHED IN AGRICULTURAL JOURNALS. Boston Soc. Nat. Hist. Proc. 9: 286–320, illus.
(28) WOODWORTH, C. W.
1889. NORTH AMERICAN TYPHLOCYBINI. Psyche 5: 211–214.

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A LABORATORY STUDY OF THE FIELD PERCOLATION RATES OF SOILS

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CONTENTS

	Page
Introduction	1
Review of the literature	2
Soil description and location	3
The soil core auger	3
Core preparation and percolation apparatus	6
Evaluation of experimental data	8
Preparation and the percolation rates of laboratory-packed soil tubes	12
Preparation of the soil samples	12
The soil tubes	12
Filling the soil tubes	13
Presaturation of the sample	13
A consideration of the experimental data from the cores and from the laboratory-packed samples	14
The correlation of percolation data with other soil properties	17
The properties studied	17
Properties which correlate with permeability	19
Erosion and soil permeability	21
Summary	22
Literature cited	23

INTRODUCTION

Permeability is unquestionably one of the most important properties of soil. In many cases it is a limiting factor of crop production and is of outstanding importance in problems of irrigation and drainage. Many attempts have therefore been made to obtain quantitative measurements of this property, but soil permeability is so complex and variable in nature that no method has yet been developed which will satisfactorily measure the rates at which water will percolate through different soils. Data are not available for a quantitative comparison of the permeability of different soil types, and the present study was undertaken for the purpose of developing a method whereby such data might be obtained.

Some methods have been proposed for measuring percolation rates of soil in situ, but to obtain data on a large number of soils by these methods is obviously impractical. Moreover, it was believed that equally reliable data could be obtained more expeditiously if undisturbed sections of soil could be obtained in the field, transported to the laboratory, and there subjected to standard conditions for percolation. Attention was therefore first directed toward methods of obtaining undisturbed cores of soil from the field, and a satisfactory apparatus was devised for this purpose. Many cores were taken with

this apparatus from several widely different soil types, and data were obtained relative to the percolation of water through these cores under uniform laboratory conditions. A study was also made of the percolation rates of these same soils on samples which had been broken down and packed artificially in percolation tubes. Finally the percolation rates of the undisturbed cores and of the artificially packed tubes were compared with other laboratory tests of the soil material.

REVIEW OF THE LITERATURE

The percolation of water through undisturbed soil sections transported to the laboratory has never been extensively studied. Davis and Adams (*2*)[1] have given data on a few such samples, but sufficient work was not done to warrant any general conclusions. Stevenson (*19*) and later Powell (*14*) have devised apparatus for taking samples in the field without disturbing their structure, but very few data have been reported on the samples obtained.

It appears that very little information is extant concerning the percolation of water through soils of undisturbed structure either from transported samples or from field studies. However, some information of a general character has been obtained through field studies of irrigation (*5*, *18*, *21*) and also through the use of lysimeters. Loughridge (*7*) found that wide variation in permeability may be expected in certain soils over comparatively small areas. Mathews (*9*) in studying the gumbo soil of the Belle Fourche irrigation project found that soil to be uniform in permeability under similar conditions, but that permeability varied markedly with the initial water content and the structural condition of the soil. Some of the data obtained from the lysimeters at Rothamsted (*12*) may be interpreted to show a seasonal variation in the permeability of the plots, indicative also of a seasonal change in the structural condition of the soil.

The percolation of water through soil samples, not representative of field structure but artificially packed in the laboratory, has been studied by many investigators. King (*6*) used sands to simplify his conditions and was thus able to verify the formulas of Schlichter (*17*) which define permeability in terms of porosity and effective particle size. Greene and Ampt (*3*) have formulated equations of more general application which relate to permeability, porosity, and capillarity, but their equations have been found by Hardy (*4*) to be inapplicable to colloidal soils. It appears, therefore, that if a general expression for permeability is sought, it must be found in terms of properties which will more effectively represent the important and complex part played by the clay fraction of the soil in governing permeability than do the equations of Greene and Ampt.

Puri (*15*) and Bouyoucos (*1*) have formulated methods for percolation experiments in which the percolation rate is apparently governed by the quality and quantity of the clay fraction in the soil, but the extent to which the results of these methods are indicative of field permeability has not been experimentally tested. For the purpose of this study it appeared more desirable to use the more

[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

familiar method of packing a loose sample of soil in a percolation tube. In this connection the work of Stubenrauch (*20*) and Winterer (*22*) aided materially in the determination of the conditions which were finally adopted for the percolation of water through the laboratory-packed samples of soil.

Since the present investigation was begun, the effect of suspended material in the percolating water in governing the percolation capacity of a soil has been shown by Lowdermilk (*8*). He concludes that the clogging of pores and seepage openings at the surface of a bare soil by such material largely accounts for the increase in run-off from such soil as compared to the run-off from the same soil covered with forest litter and thus protected at the surface.

SOIL DESCRIPTION AND LOCATION

The six soils used in this investigation are all humid forest-soil types. They are: (1) A Manor clay loam taken 1¼ miles northwest of Tysons Crossroads, Fairfax County, Va.; (2) a Leonardtown silty clay loam from two sources—vicinity of Meadows, and just south of Tom Brook, both in Prince Georges County, Md.; (3) a Davidson clay from the vicinity of Orange, Orange County, Va.; (4) a Penn loam from 2 miles north of Chantilly, Fairfax County, Va.; (5) a Norfolk loamy sand taken a mile southeast of Gunston Hall, Fairfax County, Va.; and (6) an Iredell silt loam obtained a mile southeast of Herndon, Fairfax County, Va.

With two exceptions each of these locations represented a well-sodded area. The Norfolk loamy sand cores were cut from an area sparsely covered with bunch grass, weeds, and tree seedlings. The Manor cores were cut from an old pasture where overpasturing and trampling had thinned and stunted the grass cover.

THE SOIL CORE AUGER

Figure 1 represents the auger which was used in obtaining the undisturbed soil samples as it appears when assembled and ready for use. It consists in part of a toothed steel cylindrical casing 11 inches long and $4\frac{3}{16}$ inches in outside diameter, with a cylinder wall one-sixteenth inch thick. Around the outside of the cylinder, at right angles and welded to it, is the elevating spiral of three complete turns of strap steel one-eighth inch thick. The vertical length of the spiral is 9 inches. At the lower end it terminates in a cutting blade $1\frac{1}{16}$ inches wide. The spiral itself gradually tapers from a width of $1\frac{1}{16}$ inches at the cutting blade to a width of 1 inch at the top of the spiral.

Into the top of the cylinder is pressed and riveted a cylinder head of duralumin. Through it is bored a small hole to serve as an air vent.

Centered and riveted in the cylinder head is a 3-foot shaft of cold-rolled stock steel 1 inch in diameter. A stock pipe fitting at the top of this shaft serves as a socket through which a wooden handle 18 inches long is passed by means of which the auger is turned. Throughout 21 inches of its length the shaft is threaded with a machine thread of six turns to the inch.

In order to hold the auger firmly while in use it is attached by means of a bearing block through which the shaft passes to a wooden support patterned after a carpenter's sawhorse, or trestle, about 3 feet long and 22 inches high. The one important requirement is that it be rigidly constructed.

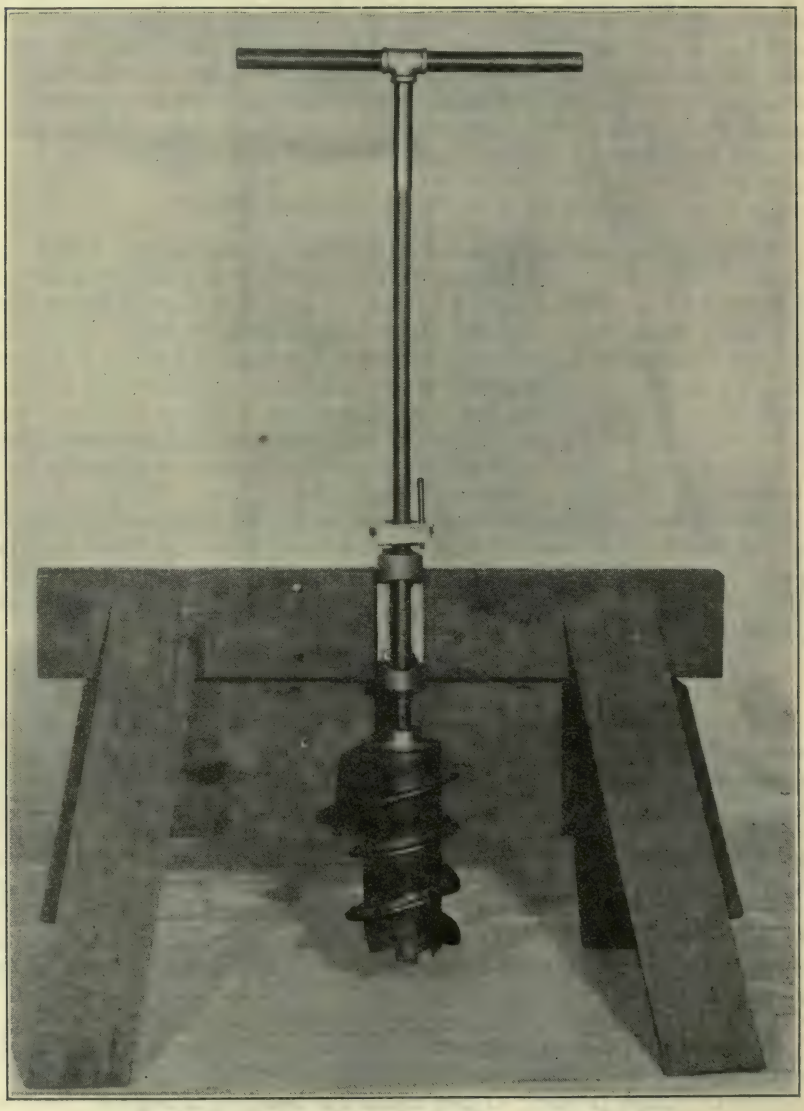

FIGURE 1.—The complete apparatus for cutting soil cores

Figure 2 shows the bearing block in more detail. This bearing block was cut from a piece of duralumin 7¼ inches long and 2½ inches in diameter. One side has been machined flat to fit flush against the 2 by 6 inch scantling of the trestle; the other side has been cut away in the center until there is left a flat bar rigidly sup-

porting a bearing at each end. Countersunk in this flat bar are two bolts 4 inches apart which are used to attach the auger to the trestle. Accurately fitting bronze bushings are used for the bearing surfaces as the duralumin does not wear well. Duralumin is used where possible for two reasons—it is easily machined and it decreases the total weight of the auger.

In order to control the rate at which the auger penetrates the earth, a thread lock or chasing nut, corresponding to the threads on the shaft previously described, is attached to the bearing block through the use of a stud bolt, on which the two halves of the thread lock are hinged. Figure 3 shows the separated halves of the thread lock. Each half consists essentially of a bronze half nut held firmly in a duralumin block. In operation the two halves of the thread lock are held together by means of a tapered pin and force the auger to enter the earth at a rate proportional to the pitch of the thread on the shaft. To remove the auger from the soil the pin is withdrawn, the two parts of the thread lock are swung apart, and the auger is lifted, without turning it, from the soil.

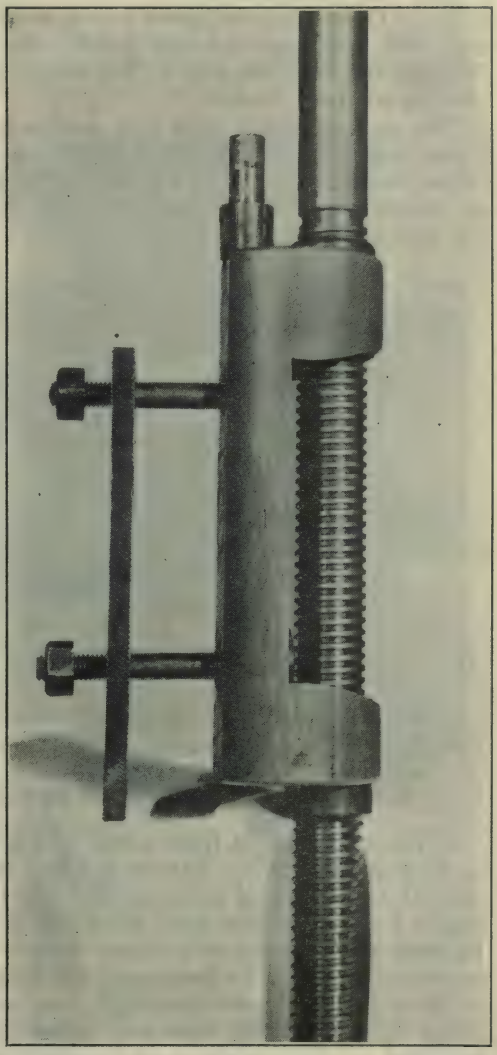

FIGURE 2.—A side view of the bearing block of the auger shown in Figure 1

Mention has been made of the teeth on the cylindrical casing of the auger. There are six of them, cut from the casing itself, equally spaced about the circumference of the cylinder. They act as colters and completely sever the core from the soil mass. This severing precedes the removal of the soil by the cutting blade and spiral. The general design of these teeth can be seen in Figure 4.

The length of the vertical cutting edge is three-fourths inch. On the reverse sloping edge the metal has been cut away in such a manner as to leave a small projection on each tooth one-fourth inch long.

By undercutting the vertical tooth edge with a continuation of the sloping cut it is possible to bend in the cutting edge of each tooth so that the core is cut smaller than the internal diameter of the cylinder casing. Each tooth is inset three-sixteenths of an inch, giving the minimum effective clearance between core and cylinder casing. Once the core is cut free from the soil mass, it is not in contact with the auger at any point. As the auger passes downward through the soil, the core is left standing as a column of soil in the interior of the cylinder.

The soils sampled with this device covered a wide range of soil types from districts near the laboratory. Cores could readily be obtained in all the varieties of soil, except where the presence of pebbles or coarse gravel in the soil impeded the boring process and caused the core to break.

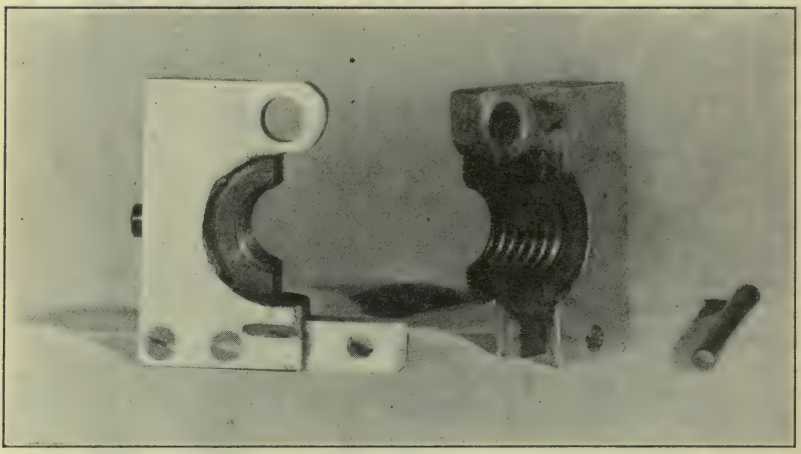

FIGURE 3.—The separated halves of the thread lock of the soil auger shown in Figure 1

CORE PREPARATION AND PERCOLATION APPARATUS

If the core was cut from a soil which was reasonably firm, it could be broken loose at the base and lifted from the hole with the hands. All subsoil cores and some surface cores on which percolation experiments have been run were removed from the hole in this manner. In cases where the condition or texture of the soil rendered the core particularly liable to breakage, the core was incased and paraffined, as described later, while still in the auger hole. Usually the core could then be broken free and lifted out. Some surface cores were removed by digging down and cutting the core free with a spade.

In all cases the cores were incased and paraffined in the field. For this purpose a cylindrical tin container was used, 4 inches in diameter and 9½ inches in length. A thin threaded brass ring, to which covers could be screwed, was soldered to each end of the container. This container was set down over the core, and the space between the core and casing was filled with melted paraffin. When the paraffin had sufficiently hardened, that part of the core projecting beyond the lower end of the casing was cut off flush with the container; the

covers were screwed in place, and the core was ready to be transported to the laboratory.

Proper paraffining of the core has been the source of some difficulty. When the core was dry, the weather warm, and the paraffin of low melting point and hot, the paraffin penetrated the core to considerable distances. On the other hand, when the core was moist and cold, and the temperature at which the paraffin was applied was proportionately too low, noticeable leaks developed between the paraffin sheath and the core. No fast rule could be laid down for avoiding such trouble. However, after some experience in paraffining the difficulty was overcome except in the case of very wet cores. It was found that cores cut in this condition had to be taken to the laboratory, dried, and reparaffined.

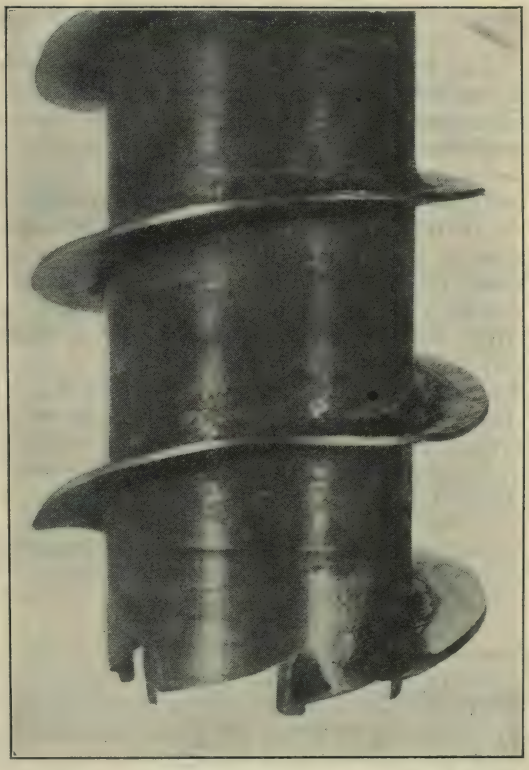

FIGURE 4.—A detailed cut showing the design of the auger teeth

For several minor reasons a paraffin melting at 45° C. was used in cool weather, and one melting at 55° C. was used in warm or hot weather.

The upper end of the cores usually presented a rough, uneven appearance when they came in from the field; in most instances it was spattered with paraffin. When brought to the laboratory this rough end was cut to a smooth surface about 1½ inches from the end of the container by means of a knife fashioned from a small spatula, sharpened, with half the blade bent at right angles to the handle. Thus the first inch of soil was removed.

To complete the preparation of the core for percolation the cover was unscrewed from the lower end of the container, and a base was substituted which resembled a funnel-shaped cap with an outlet. This cap held in place a perforated brass-plate screen which supported the core.

After being prepared, cores and containers were placed on a wooden bench support, 7 inches wide, 7 inches high, and 3 feet long, which supported the cores in batteries of six. Holes to correspond to the six containers were bored in the bench top, and the percolate was caught in beakers beneath the bench.

The distilled water for percolation was fed by means of a Mariotte constant-level device from a 5-gallon reserve bottle to an iron pipe 1 inch in diameter supported in a horizontal position along the back of the bench. The level of the pipe was 2 inches below the tops of the containers supported by the bench. This pipe served as a distributor of water to the containers and was fitted with six connections of glass and rubber tubing, each in the form of an inverted U. These connections acted as siphons and drew water over the top of the container to supply the core.

EVALUATION OF EXPERIMENTAL DATA

Field cores of the same soil varied widely in permeability even when the cores were cut from the soil within a few feet of each other. The passageways formed by cracks and fissures and the decay of roots caused a variance in flow; in some cases ant holes and wormholes made it necessary to discard the core completely. In slightly permeable soils such seriously defective cores were easily detected by their abnormally high percolation rates. In some soils the detection of a mechanically imperfect core was difficult, as a series of six cores might vary in approximately equal amounts from a relatively low to a relatively high value. In such cases cores were rejected, if, after the experiment was completed, dissection of the core revealed obvious mechanical defects. If no defects were found the values for the percolation rates were recorded. Data from cores were also discarded if the percolate showed an unusual amount of sediment or cloudiness, and if there had been abrupt and irregular changes in percolation rate. The number of cores so discarded is listed in Table 1 for each of the soils.

TABLE 1.—*Number of cores discarded from number cut*

Soil type	Depth	Cores cut	Cores discarded	Cores run
	Inches	*Number*	*Number*	*Number*
Manor clay loam	1–9	22	2	20
Do	9–17	2	1	1
Leonardtown silty clay loam, A horizon	1–9	20	2	18
Leonardtown silty clay loam, B_1 horizon	10–16	7	0	7
Leonardtown silty clay loam, B_2 horizon	18–24	3	0	3
Davidson clay	1–9	8	2	6
Penn loam	1–9	6	0	6
Norfolk loamy sand	1–9	14	0	14
Iredell silt loam, A horizon	1–6	12	8	4

Not all the cores used were of equal length. Wherever possible the length of a core was made to correspond to a soil horizon, and in no instance did it include parts of two horizons. In some soils, owing to the condition of the soil, the presence of gravel, and other factors, the difficulty in obtaining cores made it advisable to use cores of different lengths. Correction could be made for such variations in length and also for variations in water head, if the soil cores had acted mechanically as a series of tubes through which the water passed, by use of the formula

$$R=\frac{VL}{ATH}$$

where R is the rate of flow; V, the volume of water percolated; L, the length of core; A, the area of the core; T, the time; and H, the head of water above the core plus the length of the core. However, while it may be demonstrated that the head of water used and the length of the core definitely affect the rate of percolation in a soil such as Davidson clay or Norfolk loamy sand, in other soils, such as the Leonardtown and Iredell, a decided increase in head did not materially affect the percolation rate. It was therefore advisable to keep the value of H approximately equal to the value of L by adjusting the cores and the constant-level device which supplied them with water, so that only the slightest depth of water practical was maintained over the cores. This amounted to a depth of about 2 centimeters. When the water head was so adjusted the core percolation rates for any one soil came into better agreement when both H and L were eliminated from the foregoing equation. For purposes of comparison all percolation rates were calculated in terms of inches per hour.

$$R=\frac{0.3937\,V}{AT}$$

where 0.3937 is a factor to convert from the metric to the English system.

Not only did the cores vary in percolation rate from each other but the percolation rate of any individual core was found to be variable. Usually there occurred a decrease in rate with long-continued percolation regardless of the moisture content of the core at the time taken or of the apparent duration of such content in the field. The decrease occurred both in the cases where percolation was continuous and where it was intermittent. The reasons for these variations are obscure. It would seem reasonable to expect that where a soil had been soaked in the field throughout a long-continued wet period any effect due to long-continued percolation in the laboratory would have reached its maximum. This appears not to be the case.

It would appear that all cores should be run either continuously or intermittently, but this procedure was found to be impractical in this investigation. Cores through which water flowed readily would, if percolated continuously, give excessive volumes of percolate. Moreover, the slowly percolating cores drained so slowly and were resaturated so slowly that even when intermittent percolation was attempted it approximated continuous percolation.

Cores were therefore run intermittently or continuously, depending on the character of the cores. The percolation rate taken for comparison was that of the second day of the run measured over a suitable time interval. The second day of the run was chosen as a basis for comparison, for by so doing a saturated condition was obtained for all the cores. As the permeability of the cores changed on continued percolation, it was considered probable that the percolation rates taken on later days would be less representative of the field permeability than were the rates which were determined from the run of the second day. Table 2 makes evident this change in permeability with continued percolation.

TABLE 2.—*Change in soil permeability after continued percolation*

Day of run	Manor clay loam, 1 to 9 inches (6 cores)[1]		Leonardtown silty clay loam (A), 1 to 9 inches (15 cores)[1]		Davidson clay, 1 to 9 inches (6 cores)[1]		Penn loam, 1 to 9 inches (6 cores)[1]		Norfolk loamy sand, 1 to 9 inches (6 cores)[1]		Iredell silt loam (A), 1 to 6 inches (4 cores)[1]	
	Percolation	Rate per hour	Percolation	Rate per hour	Percolation	Rate per hour	Percolation	Rate per hour	Percolation	Rate per hour	Percolation	Rate per hour
	Hours	*C. c.*	*Hours*	*C. c.*	*Hours*	*C. c.*	*Hours*	*C. c.*	*Minutes*	*C. c.*	*Hours*	*C. c.*
1st	16. 5	17. 7	24	11. 3	1	440	1	122	10	1, 214	24	5. 2
1st	7. 5	10. 4										
2d	16. 5	9. 3			1	166	3	40. 8	10	1, 126	24	4. 9
2d	7. 5	7. 4										
3d					1	158	4	41. 2	10	862	24	5. 0
4th	7. 5	11. 7					4	40. 4				
4th	16. 5	10. 4							10	839	24	4. 9
5th	24	10. 5					4	34. 7				
6th	24	10. 1			1	105						
7th	24	12. 2										
8th	24	11. 6										
10th	24	15. 2			1	174						
13th					1	105						
14th					1	84						
15th					1	59						
20th					1	87						
21st					1	59						

[1] Number of cores averaged.

In the Leonardtown A-horizon cores the percolation rates used for comparison were based on the first 24 hours of the run. Contrary to the general rule, these cores had increased in percolation rate, on continued percolation, slowly at first and then more rapidly. Examination of the cores after percolation showed a puddled condition of the soil on the cylindrical surface of the core next to the paraffin seal, which indicated that the development of leaks between sheath and core accounted for the increased volumes of percolate, rather than any change in soil permeability. For this reason data on the persistence of permeability for these cores are omitted from Table 2.

With the exception of these Leonardtown cores the data presented in Table 3 are the percolation data of the second day of the run for each separate core, expressed in terms of inches per hour. The data for the Leonardtown A-horizon cores are based on the first 24 hours of run and were accepted only after six of the cores, dried and reparaffined in the laboratory, had given approximately the same values as those previously obtained. The data of Table 3 for each type of core have been averaged and are given in Table 4 for comparison with the average percolation values obtained from the laboratory-packed soil tubes.

TABLE 3.—*Data pertaining to the separate cores in soil percolation*

Soil and location	Date of taking sample	Moisture content	Length of core	Area	Duration of percolation	Rate per hour
		Per cent	*Cm.*	*Sq. cm.*	*Hours*	*Inches*
Manor clay loam (1 to 9 inches), northwest of Tysons Crossroads, Va.	Sept. 5, 1929	(1)	19.7 17.8 21.5 21.5 20.9 19.7	66	24	0.038 .083 .081 .060 .043 .023
Average						.055
Do	Sept. 19, 1929	5	20.3 19.8 20.1 20.3 19.7	68	24	.164 .079 .128 .148 .130
Average						.130
Do	Sept. 25, 1929	10.6	18.2 19.7 16.8 18.3 17.3	65	24	.050 .156 .106 .140 .230
Average						.136
Manor clay loam (9 to 17 inches), location as above	Mar. 21, 1930		18.0	64	24	.032
Leonardtown silty clay loam, A (1 to 9 inches), Meadows, Md.	Oct. 14. 1929	27.5	21.6 21.4 21.3 20.8	65	24	.114 .078 .055 .085
Average						.083
Leonardtown silty clay loam, A (1 to 9 inches), Tom Brook, Md.	Oct. 21, 1929	21.2	21.0	65	24	.068 .036 .020 .040 .025 .040
Average						.038
Do	Oct. 25, 1927	20.0	21.0	65	24	.181 .144 .074 .033 .037
Average						.094
Leonardtown silty clay loam, B_1 (10 to 16 inches), Tom Brook, Md.	Oct. 14, 1929		18.0 20.0	65	24	.075 .021
	Oct. 21, 1929		21.0 21.0			.028 .045
	Jan. 17, 1930		14.0 17.0 11.0	64		.012 .057 .049
Average						.041
Leonardtown silty clay loam, B_2 (18 to 24 inches), Tom Brook, Md.	Oct. 25, 1927		13.0	64	24	.032
	Jan. 1, 1930		12.0 13.0	64		.024 .018
Average						.025
Davidson clay (1 to 9 inches), Orange, Va.	Nov. 13, 1929	20.0	20.3 19.8 19.8 20.5 20.6 20.3	64	1	.625 .755 1.060 2.870 .572 .272
Average						1.026

[1] Less than 5 per cent.

TABLE 3.—*Data pertaining to the separate cores in soil percolation*—Continued

Soil and location	Date of taking sample	Moisture content	Length of core	Area	Duration of percolation	Rate per hour
		Per cent	*Cm.*	*Sq. cm.*	*Hours*	*Inches*
Penn loam (1 to 9 inches), north of Chantilly, Va	Jan. 8, 1930	18.9	21.0	64	3	0.067 .287 .307 .460 .051 .307
Average						.247
					Minutes	
Norfolk loamy sand (1 to 9 inches), Gunston Hall, Va	Feb. 18, 1930	8.5	20.0	64	10	5.450 7.700 7.700 7.700 6.750 5.600
Average						6.817
					Hours	
Iredell silt loam, A (1 to 6 inches), Herndon, Va	Apr. 1, 1930	15.0	13.0 14.0 15.0 14.0	64	24	.016 .065 .010 .029
Average						.030

PREPARATION AND THE PERCOLATION RATES OF LABORATORY-PACKED SOIL TUBES

In the attempt to get a comparison between the percolation rates as determined by a study of the cores and the percolation rates of the soils determined on laboratory-packed samples, the usual difficulty in securing duplicate results with the laboratory-packed sample was constantly encountered. After a number of trials the following procedure was adopted as the most satisfactory. Its effectiveness can be estimated by an examination of columns 4 and 5 of Table 4 which give the maximum and minimum values encountered in the number of determinations listed in column 3.

PREPARATION OF THE SOIL SAMPLES

Preferably, the soil used in percolation experiments was taken from the field in its optimum moisture condition. It was then broken into small lumps about the size of a walnut and allowed to become air-dry slowly until the tendency of a slightly moist soil to pack and flake under the rolling-pin was no longer evident. In this condition the soil was crushed to pass through a 2-millimeter screen by rolling it with an ordinary wooden rolling-pin. A maximum of pressure, as exerted by an average individual, was used in rolling the soil, but the amount of rolling which the soil received was kept at a minimum by sieving frequently. Taken in its entirety, this procedure apparently gives duplicable results, and the degree of fineness obtained for any soil is more characteristic of the soil than would be the case if a minimum of rolling only were specified.

THE SOIL TUBES

The tubes used to contain the soil during the percolation experiments were standard-equipment brass tubes, 10 inches long and 2

inches in diameter. A cast-brass base, corrugated on its upper surface, is soldered into the bottom of the tube. A perforated brass disk rests on the corrugated surface and allows free drainage of the percolated water. Filter papers are not used because of their tendency to become clogged with soil colloid. The tops of the tubes are fitted with connections so that they can be attached in series with rubber tubing to a constant-level device and be supplied with a constant water head.

FILLING THE SOIL TUBES

In filling the soil tubes a large spatula was used, carefully inserted so that the heap of soil it carried could be plumped into the tube by quickly removing the spatula. The mechanical segregation of soil particles which occurred when the soil was simply poured into the tube was thus partly avoided. Unless the tubes were filled in this way, the accumulation of coarse particles at the walls of the cylinder produced a rate of percolation not characteristic of the bulk of the soil. The tubes were filled with soil and uniformly packed. It was not necessary to weigh the amount of soil in each tube, for differences in weight of as much as 50 grams were shown to have no appreciable effect on the percolation rates. In order to get the tube full of packed soil, the soil was settled occasionally during the filling process by dropping the tube from 8 to 12 times against a stone block. The way in which this was done becomes evident from a description of the manner in which the soil was further packed. In order to complete the packing of the soil after the soil tube had been filled, the tube was held in an upright position and continuously dropped from a height of 2 centimeters to the stone block, rotating the tube 90° between each four impacts. This was continued until the point at which further settling could be observed had been passed. With practice the tube could be dropped uniformly for one and one-half minutes at a rate of 120 times per minute.

PRESATURATION OF THE SAMPLE

After the tubes were filled and packed the soil was saturated with water. This was accomplished by placing the tubes in a jar of distilled water, immersing them to a depth of 9 inches, and allowing them to remain overnight or longer if necessary for complete saturation. This procedure not only saturated the soil by upward displacement of the air, but produced slaking, settling, shrinking, or swelling, and such other alterations as are analogous to the changes that take place when dry soil is saturated by rainfall in the field.

After saturation the soil tubes were placed on a rack, connected to a constant-level device, and after 10 minutes or so of preliminary percolation, the receiving vessels were emptied, and the percolation rate over a 4-hour period was measured. The results of these percolation experiments are given as average values in Table 4. They will be considered in conjunction with the corresponding percolation values which were obtained from the study of the soil cores.

A CONSIDERATION OF THE EXPERIMENTAL DATA FROM THE CORES AND FROM THE LABORATORY-PACKED SAMPLES

Consideration of the data presented in columns 7 and 8 of Table 4 reveals a surprising degree of correlation between the results obtained on field cores and on laboratory-packed samples for five of the six surface soils studied, and an equally surprising lack of correlation for the subsoils and for the A horizon of the Norfolk loamy sand. If attention is confined to the surface soils, the following statements may be made: (1) The percolation order of the laboratory-packed samples is the same as that of the soil cores, except in the case of the Leonardtown and Iredell soils; and (2) in four cases percolation is more rapid through the core than through the corresponding soil tube, whereas in two cases, with the Manor and Iredell soils, the reverse is true.

TABLE 4.—*Variation of tube-percolation values and a comparison of average values determined by means of cores and tubes*

Soil	Depth	Percolation tubes	Amount percolated in 4 hours			Rate per hour calculated from—		Cores averaged
			Maximum	Minimum	Average	Tubes	Cores	
	Inches	*Number*	*C. c. per hour*	*C. c. per hour*	*C. c. per hour*	*Inches*	*Inches*	*Number*
Manor clay loam	1–9	8	42	36	39	0.202	0.104	16
Do	9–14	4	21	20	20.5	.106	.032	1
Leonardtown silty clay loam, A	1–9	8	13	9	11	.057	.069	15
Leonardtown silty clay loam, B_1	10–16	4	53	45	49	.254	.041	7
Leonardtown silty clay loam, B_2	18–24	13	26	17	21	.108	.025	3
Davidson clay	1–9	12	244	132	182	.940	1.020	6
Do	9–17	4	91	64	77.5	.401		
Penn loam	1–9	8	50	43	46	.238	.247	6
Norfolk loamy sand	1–9	8	560	510	538	2.780	6.820	6
Iredell silt loam, A	1–9	8	14	11	12	.062	.030	4

The faster percolation rate for the cores of Leonardtown, Penn, Norfolk, and Davidson soils can not be due to a greater porosity of the core. Were this the case the volume weight of the cores would be less than that of the corresponding laboratory-packed samples. The volume-weight data presented in Table 6 show the reverse to be true. The higher rate can be accounted for by assuming that part of the percolation through the core was a filtration of water through root channels or the natural structural passageways in the soil.

This explanation is made more probable by a consideration of the behavior of the Norfolk loamy sand cores. The average percolation rate of these cores was 6.82 inches per hour, whereas that of the laboratory samples was 2.78 inches. This is an exceptionally wide variation and might be assumed to be due to local causes not characteristic of the soil in general. Consequently, another lot of cores was cut representative of three different locations in the vicinity from which the original cores were taken. The data on these cores are given in Table 5. A decrease from the original rate to 5.49, 3.25, and 3.93 inches per hour occurred, but the difference between the natural and artificial cores was still very large.

TABLE 5.—*Percolation data on additional soil cores not included in Tables 3 and 4*

Soil and location	Date of taking sample	Location description	Rate of percolation per hour—		Average, inches
			In cubic centimeters	In inches	
Norfolk loamy sand (1 to 9 inches); Gunston Hall, Va.	Mar. 18, 1930	Grassy ridge	864	5.20	5.49
		do	924	5.60	
		do	936	5.66	
		Bare depression	552	3.34	3.25
		do	420	2.54	
		do	642	3.88	
		Forest	474	2.86	3.93
		do	828	5.00	
Manor clay loam (1 to 9 inches); northwest of Tysons Cross-roads, Va.	Mar. 21, 1930	Heavily sodded	2.1	.013	.018
			2.3	.014	
			5.3	.032	
			.0	.000	
			5.0	.031	
			2.9	.018	
Leonardtown silty clay loam, A (1 to 9 inches); Tom Brook, Md.	Jan. 17, 1930	Grassy level	1.5	.009	.00
			1.94	.012	
			1.23	.007	

An examination of these cores after percolation showed the cause of their rapid rates of percolation. Throughout the soil there were small passageways, free from silt and clay, between the sand grains, which formed excellent channels for the conduction of water through the soil. This structural condition was not found in the laboratory-packed samples; consequently, even if the effect of differences in volume weight be ignored, from 14 to 59 per cent of the percolation through field cores was due to the passageways.

It appears reasonable that in soils of heavier texture and well-developed structure, the passageways due to soil structure, as well as channels of other types, may affect greatly the rate of percolation. Qualitative evidence that this assumption is justified was obtained by allowing a solution of ponceau dye to percolate through a previously saturated core of Manor subsoil. In four hours dye appeared in the percolate although but 25 cubic centimeters of liquid had passed through the core. On dissection of the core, staining with the dye was found only along the surfaces of natural cleavage and root channels. Since it required 400 cubic centimeters of water to saturate the core, and color appeared in the filtrate when but 25 cubic centimeters had passed, it is clear that much of the percolation took place along the passageways where the dye was deposited rather than through the whole soil mass.

Careful examination of the surface cores of the Penn, Manor, Leonardtown, and Iredell surface-soil cores revealed no structural conditions which could be considered greatly effective in increasing the percolation rate. The Penn and Leonardtown cores showed a more rapid percolation than the laboratory-packed samples, whereas the reverse was the case for the Manor and Iredell cores. If the increased rate were to be ascribed to root channels, the slower rate of the Manor soil might possibly be explained by their absence. As previously stated, the first Manor cores were obtained from an old pasture where overpasturing and trampling had thinned and stunted the grass cover. This might have resulted in a more than normal silting shut of old passageways and less development of new chan-

nels. To test this a second set of cores was obtained from a heavily grassed area about 50 yards from the previous location. The results of tests on these are found in Table 5. Contrary to expectation, these samples proved to be less pervious than the ones previously obtained, and the explanation of the behavior of the earlier samples remains in doubt.

The two lots of Manor cores were obtained in September and March. Three Leonardtown surface cores cut in January gave a percolation rate less than that obtained on cores of the same soil cut the previous October. (Tables 4 and 5.) It appears, therefore, that these soils become less permeable during the winter months, a conclusion apparently in harmony with the results obtained at Rothamsted (*12*). This also explains the inversion of the percolation rates of the Leonardtown and Iredell cores shown in Table 4, since the Leonardtown cores were cut in October and the Iredell cores in early April. If the samples of Leonardtown cut in January are compared with samples of Iredell cut in April, then the order is the same as in the laboratory-packed samples. As both of these soils may be considered structureless, the permeability of their cores should fall in the same order as the permeability of the packed soil samples.

There is no infallible evidence that seasonal alteration of the percolation rate is characteristic of soil texture, but it appears probable that sands and loams are relatively less affected than are clay and silty soils. The Norfolk cores taken in the spring had a very rapid percolation rate, whereas the Penn cores, also taken in the spring, had almost the same rate as in the laboratory-packed samples.

Because of the evidence which tends to show that structure plays so large a part in determining the field permeability of a soil, minor significance is attached to the correlation found in this investigation to relate the percolation rates of the surface-soil cores and the laboratory-packed samples, since only two of the six, from the standpoint of percolation, can be said to have structure. These are the Davidson and Norfolk soils. The tube-percolation rate for the Davidson was reasonably high, as the soil on rolling breaks down into small granular particles which like sand are effective in producing a high percolation rate. The "structure" of the Norfolk loamy sand is completely lost on rolling, with a consequent wide variation between the rates of cores and tubes. Presumably soils may be found which will be relatively dense and impermeable in the field, and, by reason of the manner in which they break on rolling, will give a high percolation rate for the packed sample. Houston clay apparently exemplifies this type.[2]

For a soil under cultivation, the percolation rate determined on a laboratory-packed series of tubes may be a reliable gage of permeability, but the value of such a determination is limited by the relative permeability of the underlying subsoil. As drainage water penetrates through the soil, the downward flow is constantly governed by the least pervious of the soil horizons through which the water passes. The percolation rate shown by a subsoil determines whether a secondary run-off takes place either on, or beneath the soil

[2] A Houston black clay subsoil, between depths of 24 and 36 inches, from Temple, Tex., had a percolation rate of 5.65 inches per hour. This value is the average of four laboratory-packed samples. No field cores were obtained, hence no direct comparison is possible.

surface, and that of the A horizon determines primary surface flow for a given rainfall.

Still another factor is involved in the percolation rate of surface soils. In soils having large capillaries, or in which root channels or other passageways are frequent, the soil air may escape as rapidly as the rainfall supplies water to take its place. However, in fine-grained soils which are underlain by a nonporous stratum of rock or clay, the rainfall may, and apparently does, seal the surface soil and prevent the escape of air. Continued percolation by capillarity then results in the development of an air pressure of considerable magnitude within the soil, and this appreciably alters the rate of percolation as measured by a soil core or a laboratory-packed sample of soil open at the lower end. It follows that an impermeable lower horizon may be effective in retarding percolation before it has been reached by the percolating water.

THE CORRELATION OF PERCOLATION DATA WITH OTHER SOIL PROPERTIES

THE PROPERTIES STUDIED

A study of the percolation data obtained both from cores and laboratory-packed samples shows that the latter alone are not a sufficient index to field percolation rates, nor do field cores yield satisfactory results unless large numbers are studied under conditions that take into account the seasonal and other variations to which they are subject. The application of both methods to the six surface soils used in the investigation results in placing these six soils in the same order of permeability in each case and establishes that order with reasonable certainty. It offers, therefore, an excellent basis for a study of the correlation of other soil functions with percolation.

The results obtained by Middleton (*11*) in determining the erosiveness of soils by indirect methods place emphasis on this plan of attacking the problem of percolation and aided in determining the general direction of the research. In consequence, measurement of a series of properties of the soils under investigation was made. This series included all physical properties which were thought to be influenced by, or to have any influence on, permeability. The results of this study are presented in Table 6. The direct measurements of mechanical analysis, the volume weight of both cores and laboratory-packed samples, the colloid by water absorption, the moisture equivalent, the water-holding capacity, and the suspension per cent are given in the table. Included also are values derived from the direct measurements—the ratio of colloid to moisture equivalent, the dispersion ratio, the erosion ratio, and the percolation ratio.

TABLE 6.—*Physical measurements and mechanical analyses of soils studied*

Sample No.	Soil type	Depth	Mechanical analysis [1]							
			Fine gravel, 2–1	Coarse sand, 1–0.5	Medium sand, 0.5–0.25	Fine sand, 0.25–0.1	Very fine sand, 0.1–0.05	Silt, 0.05–0.005	Clay, 0.005–0	Colloid, 0.002–0
		Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
5882	Manor clay loam	1–9	1.2	1.9	3.1	11.7	11.2	44.1	25.2	15.0
5883	Manor clay loam (subsoil of 5882)	9–17	.6	1.5	2.5	9.6	9.7	45.3	30.4	19.2
5884	Leonardtown silty clay loam, A horizon	1–9	.6	1.8	3.2	4.9	5.8	58.6	23.5	12.5
5885	Leonardtown B_1 horizon (subsoil of 5884)	10–16	.1	.7	1.8	2.8	4.2	52.7	37.3	26.7
5886	Leonardtown B_2 horizon (subsoil of 5884)	18–24	.2	2.2	5.4	10.8	6.9	40.2	34.3	24.8
5887	Davidson clay	1–9	.9	1.8	1.3	2.5	2.5	24.3	66.0	55.0
5888	Davidson clay (subsoil of 5887)	9–17	.9	1.5	1.2	1.9	1.9	29.8	62.9	51.4
5889	Penn loam	1–9	1.2	4.6	5.9	16.3	10.7	41.2	18.8	12.6
6113	Norfolk loamy sand	1–9	.2	8.1	29.9	39.3	6.1	8.7	6.9	4.3
6114	Iredell silt loam	1–6	1.8	3.8	4.0	9.7	10.9	51.2	17.0	9.1

Sample No.	Soil type	Volume weight from soil core	Volume weight from packed soil sample	Colloid by water absorption	Moisture equivalent	Water-holding capacity	Ratio of colloid to moisture equivalent	Suspension per cent [2]	Disperison ratio	Erosion ratio	Percolation ratio
5882	Manor clay loam	1.38	1.34	12.5	26.3	45.2	0.475	20.92	30.2	63.6	44.0
5883	Manor clay loam (subsoil of 5882)	------	------	14.4	23.5	36.2	.611	34.64	45.8	75.8	56.5
5884	Leonardtown silty clay loam, A horizon	1.40	1.38	9.85	22.9	36.7	.430	42.20	52.5	122.0	98.5
5885	Leonardtown B_1 horizon (subsoil of 5884)	------	------	22.4	25.7	37.1	.871	43.68	48.5	55.7	50.1
5886	Leonardtown B_2 horizon (subsoil of 5884)	------	------	24.1	21.5	35.6	1.12	24.72	33.2	29.8	22.0
5887	Davidson clay	1.45	1.38	47.3	29.7	44.4	1.59	13.20	14.6	9.17	8.3
5888	Davidson clay (subsoil of 5887)	------	------	46.6	28.0	42.6	1.66	20.36	23.0	13.8	12.2
5889	Penn loam	1.45	1.42	11.4	20.1	39.2	.566	22.08	37.0	65.2	39.0
6113	Norfolk loamy sand	1.60	1.45	3.79	7.15	32.7	.530	3.96	25.4	48.8	7.47
6114	Iredell silt loam	1.60	1.50	7.74	19.4	36.8	.399	31.5	46.2	116.0	78.9

[1] Analyses by L. T. Alexander.
[2] Determinations by H. E. Middleton.

It is of course recognized that there is a distinct relation between the physical properties of the soils and their chemical composition. This is particularly important in the case of the colloids. Since, however, the physical properties alone are directly involved, no attempt is made to include chemical considerations in the present investigation.

The mechanical analyses of these soils were made by methods outlined by Olmstead, Alexander, and Middleton (*13*). The quantity of colloid was determined by the water absorption method over 3.3 per cent sulphuric acid (*16*). The moisture-equivalent determinations followed the procedure outlined by Middleton (*10*). The dispersion and erosion ratios are defined by Middleton (*11*, *p. 2–3*) in his bulletin on soil erosion as follows:

A sample of air-dry soil equivalent to 10 grams of oven-dry soil was placed in a tall cylinder of approximately 1,200 cubic centimeter capacity fitted with

a rubber stopper. Sufficient distilled water was added to make the volume a liter. The cylinder was closed with the stopper and was shaken end over end 20 times. The suspension was then allowed to settle until a 25 cubic centimeter sample which was pipetted at a depth of 30 centimeters consisted of particles of a maximum diameter of 0.05 millimeter. * * * From the dry weight of the pipetted fraction, the total weight of silt and clay in the suspension was calculated. The ratio, expressed in percentage, of the silt and clay so determined to the total silt and clay obtained by mechanical analysis is called the dispersion ratio. The erosion ratio is the quotient obtained by dividing the dispersion ratio by the ratio of colloid to moisture equivalent.

Throughout this bulletin the total weight of silt and clay in suspension is designated the suspension per cent. The percolation ratio is obtained by dividing the suspension per cent by the ratio of the colloid to the moisture equivalent.

The determination of the water-holding capacity was made by centrifuging samples of soil as in the determination for the moisture equivalents. The moisture-equivalent boxes, containing the moist, undisturbed, centrifuged samples, were then placed in a vessel containing water about a centimeter in depth and resaturated. They were allowed to drain overnight before the percentage of water held, based on the weight of the oven-dried soil, was determined.

The volume-weight determinations were made as follows: The volume-weight values for the cores were obtained by weighing, measuring the dimensions of a core, then correcting for moisture content. These values are relative rather than exact. The volume weights for the samples packed in the tubes were obtained by a mechanical measurement of the volume of the tube occupied by a known weight of the compacted soil.

Not all the data in Table 6 appear to have a bearing on percolation. The water-holding capacity was determined in the manner described in an attempt to correlate the packing the soil received at a 1,000 gravity with field porosity and permeability. No correlation is apparent. The use made of the volume-weight determinations has been previously stated (p. 14). There is no apparent relationship between the order of permeability of the soils and the erosion ratio or the ratio of colloid to moisture equivalent. The mechanical analyses show only that the silt percentages fall in the order of permeability for the surface soils.

PROPERTIES WHICH CORRELATE WITH PERMEABILITY

The soil functions for which a relationship to permeability is found are assembled in Table 7. For the surface soils this table shows a correlation between the order of permeability and the percentages of silt the soils contain. The percolation ratio places the soils in the same order, and the suspension per cent approximates the same order very closely. None of these values appear to be related to the observed percolation rates for the subsoils, but in this connection it should be mentioned that the difference in physical condition of the subsoils in the field probably had a greater effect in determining the effective particle size and soil condition when the soils were rolled to pass through a 2-millimeter mesh sieve than was the case with the surface soils. This would in turn affect their percolation rates but not necessarily to the same degree in each case. The silt percentages, the suspension per cent, and the percolation ratio

fall in the same order for the second group, with one exception. Several discrepancies appear, however, if an attempt is made to combine the two groups of surface soils and subsoils. On the basis of the correlation that appears in the surface-soil group, all three factors are related to percolation, but at present there is no experimental evidence to determine which of the three criteria is most representative of relative soil permeability.

TABLE 7.—*The correlation of percolation data with other soil functions*

SURFACE SOILS

Soil	Percolation rate		Silt per cent	Suspension per cent	Percolation ratio
	Cores	Tubes			
Norfolk loamy sand	6.82	2.78	8.7	3.96	7.47
Davidson clay	1.02	.940	24.3	13.20	8.30
Penn loam	.247	.238	41.2	22.08	39.0
Manor clay loam	.104	.202	44.1	20.92	44.0
Iredell silt loam	.030	.062	51.2	31.5	78.9
Leonardtown silty clay loam	[1].069	.057	58.6	42.2	98.5

SUBSOILS

Davidson clay		0.401	29.8	20.36	12.2
Leonardtown silty clay loam, B_1	0.041	.254	52.7	43.68	50.1
Leonardtown silty clay loam, B_2	.025	.108	40.2	24.72	22.0
Manor clay loam	.032	.106	45.3	34.64	56.5

[1] The percolation rate of the Leonardtown surface cores cut in January averaged only 0.009 inch per hour. (Table 5.)

Qualitatively, the relationship of the silt percentage to percolation is fairly clear. The investigation of a number of silt fractions from different types of soil has indicated that all silts are only slightly permeable; consequently the presence of a clay or colloid in a silt could not decrease the permeability to any great extent. On the other hand, the addition of certain types of colloid to a silt would result in the formation of aggregates of silt and colloid, give structure to the soil, and thus increase the percolation rate. The permeability of this hypothetical soil would necessarily vary widely, depending on the extent to which its structure could be maintained, as all clay soils are potentially impermeable; that is, they are impermeable or only slightly permeable in a puddled or compacted condition.

The addition of sand to a silt increases the rate of percolation by increasing the effective diameter of the soil grains. This type of increased permeability is subject to less variation than the type of permeability due to the formation of aggregates through the binding power of soil colloids. But since an increase of either sand or clay may increase the permeability of soils, it is not surprising that, in the series of soils used in this investigation, formed by similar conditions of weathering and containing comparatively similar colloidal material, a decrease in silt content should correspond to an increased permeability.

The values for the suspension per cent are affected by the quantity and quality of the clay or colloid present in the soil as well as by the percentage of silt it contains. The suspension per cent may,

therefore, have a wider application than the silt percentages alone as an index of permeability. The colloid in a soil may act either to increase or to decrease the suspension per cent, depending on the extent to which it binds the silt into stable aggregates and the extent to which it is itself dispersed. The suspension per cent is consequently related to soil structure, particularly to the stability of field structure (as related to percolation) when the soil is in a saturated condition. It is also a measure of the rate at which the natural water passageways through the soil are sealed by the sediment carried in both the percolation and the run-off water. The importance of the effect of such sedimentation on percolation has been emphasized by Lowdermilk (*8*).

When the suspension per cent values are modified by dividing them by the ratio of the colloid per cent to the moisture equivalent, the percolation ratio is obtained. This again places the soils in the order of their percolation rates as directly determined, and so far as conclusions may be drawn from the data of this research, is a more accurate representation of relative permeability than is the suspension per cent. One criticism is pertinent both to the suspension per cent and the percolation ratio. No approximately constant value can be wholly representative of the variable permeability of a clayey soil.

EROSION AND SOIL PERMEABILITY

Middleton (*10*) found it desirable to include the ratio of colloid to moisture equivalent in his erosion ratio and suggests a probable physical interpretation of the former, that a high value for this ratio should indicate a low water-holding capacity for the soil, and therefore probably a high rate of percolation. The very probable relationship between percolation and erosion and the similarity of the erosion ratio to the percolation ratio make it desirable to conclude this bulletin with a critical comparison of these two values.

The erosion ratio (E. R.) may be expressed as follows:

$$\text{E. R.} = \frac{100 \times \text{suspension per cent}}{\text{Total per cent of silt and clay}} \times \frac{\text{Moisture equivalent}}{\text{Colloid per cent}}$$

and in like manner the percolation ratio—

$$\text{P. R.} = \frac{\text{Suspension per cent}}{1} \times \frac{\text{Moisture equivalent}}{\text{Colloid per cent}}$$

These two formulas differ only by the factor—

$$\frac{100}{\text{Total per cent of silt and clay}}$$

which is included in the erosion ratio and become identical for a hypothetical soil consisting of 100 per cent silt and clay. The expressed difference becomes increasingly greater with increased percentages of sand in the soil and justifies the belief that the erosion ratio may not fully represent the erosiveness of a soil which disintegrates into small stable particles on slaking in water and which

does not give a corresponding increase in the amount of material readily suspended. Such a soil would give a small erosion ratio and yet like sandy soils be rather readily eroded.

For certain soils the percolation ratio may likewise lead to erroneous conclusions. A stratum of hardpan is unquestionably impermeable in the field, yet it is probable that the suspension per cent determined for such a material would result in a low percolation ratio, thus indicating a highly permeable soil.[3] The derived expression does not fully take into consideration all the properties of the soil in the field.

The available data which support the validity of both the percolation and the erosion ratio seem to indicate that erosion is inversely proportional to percolation in terms of the quantities involved in the percolation ratio. The exceptions just considered seem to point to the necessity of including some other property which qualitatively is the field disintegration value of the soil. In terms of this property erosion is directly proportional to percolation. It appears probable, therefore, that the evaluation of this soil property in terms comparable with those already considered should be the object of further investigation. Success in this direction may lead to a much more satisfactory method of determination and mode of expression of both the erosivity and permeability of soils.

SUMMARY

The work done during the investigation and the conclusions reached as a result may be summarized as follows:

A soil-core auger has been devised that will satisfactorily cut cores of undisturbed soil. It is simple in design and easily constructed.

A procedure has been developed for the evaluation of the percolation rates of soil cores.

A procedure has been standardized for the measurement of the percolation rates of laboratory-packed samples of soil.

The causes of the variation in percolation rate between laboratory-packed samples and field cores of the same soil were studied.

The order of permeability for six surface soils has been established. The percentages of silt these soils contain, the suspension per cent, and the percolation ratio have been found to represent the same order. The suspension per cent and the percolation ratio are valuable criteria of relative field permeability.

The field-percolation rate of a soil is governed more by the water passageways it contains (root channels or structural cleavage) than it is by the character or volume of the pore space of the soil mass. The percolation rates of cores serve as a means of studying field permeability, but these rates vary too widely for cores of the same soil to attempt to fix field-percolation rates by this means alone, unless large numbers of cores are obtained.

The ratios for erosion and for the permeability of soils show that these properties are inversely proportional in terms of the factors of the percolation ratio.

[3] Attention is called to the relatively low percolation ratio obtained from the Leonardtown silty clay loam, B_2. See Table 7.

LITERATURE CITED

(1) Bouyoucos, G. J.
1930. A new method of measuring the comparative rate of percolation of water in different soils. Jour. Amer. Soc. Agron. 22: 438–445.

(2) Davis, R. O. E., and Adams, J. R.
1928. Methods for physical examination of soils. First Internatl. Cong. Soil Sci. Proc. and Papers 1: 434–442.

(3) Greene, W. H., and Ampt, G. A.
1911. Studies on soil physics. Part I. Flow of air and water through soils. Jour. Agr. Sci. [England] 4: 1–24.

(4) Hardy, F.
1925. Percolation in colloidal soils, considered in relation to swelling and cohesiveness. Jour. Agr. Sci. [England] 15: [434]–443.

(5) Israelsen, O. W., and West, F. L.
1922. Water-holding capacity of irrigated soils. Utah Agr. Expt. Sta. Bul. 183, 24 p., illus.

(6) King, F. H.
1899. Principles and conditions of the movements of ground water. U. S. Geol. Survey Ann. Rpt. (1897/98) 19 (pt. 2): 67–294, illus.

(7) Loughridge, R. H., under the direction of Fortier, S.
1908. The distribution of water in the soil in furrow irrigation. U. S. Dept. Agr., Off. Expt. Stas. Bul. 203, 63 p., illus.

(8) Lowdermilk, W. C.
1930 Influence of forest litter on run-off, percolation, and erosion. Jour. Forestry 28: 474–490, illus.

(9) Mathews, O. R.
1916. Water penetration in the gumbo soils of the Belle Fourche reclamation project. U. S. Dept. Agr. Bul. 447, 12 p., illus.

(10) Middleton, H. E.
1920. The moisture equivalent in relation to the mechanical analysis of soils. Soil Sci. 9: 159–167, illus.

(11) ———
1930. Properties of soils which influence soil erosion. U. S. Dept. Agr. Tech. Bul. 178, 16 p.

(12) Miller, N. H. J.
1906. The amount and composition of the drainage through unmanured and uncropped land, Barnfield, Rothamsted. Jour. Agr. Sci. [England] 1: 377–399, illus.

(13) Olmstead, L. B., Alexander, L. T., and Middleton, H. E.
1930. A pipette method of mechanical analysis of soils based on improved dispersion procedure. U. S. Dept. Agr. Tech. Bul. 170, 23 p., illus.

(14) Powell, E. B.
1926. A new soil core sampler. Soil Sci. 21: [53]–56, illus.

(15) Puri, A. N.
1929. A new percolating cylinder and some of its uses. Agr. Jour. India 24 (pt. 6): 408–412, illus.

(16) Robinson, W. O.
1922. The absorption of water by soil colloids. Jour. Phys. Chem. 26: 647–653.

(17) Schlichter, C. S.
1899. Theoretical investigation of the movement of ground water. U. S. Geol. Survey Ann. Rpt. (1897/98) 19 (pt. 2): 301–328, illus.

(18) Scofield, C. S.
1924. The movement of water in irrigated soils. Jour. Agr. Research 27: 617–694, illus.

(19) Stevenson, W. H.
1908. A new soil sampler. Iowa Agr. Expt. Sta. Bul. 94, 31 p., illus.

(20) Stubenrauch, A. V.
1902. A laboratory study of the percolation of water through soils. Calif. Agr. Expt. Sta. Rpt. 1899–1901 (pt. 2): 153–172.

(21) Widtsoe, J. A., and McLaughlin, W. W.
1912. The movement of water in irrigated soils. Utah Agr. Expt. Sta. Bul. 155, p. [19]–268, illus.

(22) Winterer, E. V.
1923. Percolation of water through soils. Calif. Agr. Expt. Sta. Ann. Rpt. 1922–23: 234–237, illus.

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APANTELES THOMPSONI LYLE, A BRACONID PARASITE OF THE EUROPEAN CORN BORER

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CONTENTS

	Page
Introduction	1
Distribution and host relations	2
Climate and agriculture of favored habitat	3
Economic importance of *Apanteles thompsoni*	3
Descriptions	4
Adult	4
Egg	5
First-stage larva	6
Second-stage larva	8
Last-stage larva	8
Pupa	12
Cocoon	12
Biology	12
Behavior under laboratory conditions	12
Oviposition	13
Biology—Continued.	
Development of the egg	14
Discussion of the embryonic envelope	15
Larval growth and pupation	18
Life of the adult	19
Effect of parasite on host	19
Seasonal history	20
Limiting factors	21
Thelyotoky	22
Economic importance of thelyotoky in the hymenopterous parasites	23
Methods of quantity collection and shipment	24
Summary	25
Literature cited	26

INTRODUCTION

The gregarious braconid parasite *Apanteles thompsoni* Lyle[2] was first mentioned in literature in 1927, when it was described by Lyle (*11*)[3] as a new species from specimens collected in northern France. W. R. Thompson and H. L. Parker, of the United States Bureau of Entomology at the European parasite laboratory, Hyères, Var, France, first found it in larvae of *Pyrausta nubilalis* Hübn., in Artemisia, near Brussels, Belgium, in 1920. In their bulletin on this insect and its controlling factors in Europe (*25*) they give a brief discussion of the biology, limiting factors, and extent of parasitism by this species.

[1] The writer expresses his appreciation to H. L. Parker, under whose direction these studies were carried on, for his inspiration and willing advice which have been of invaluable aid; to H. D. Smith, a laboratory associate, for his many helpful suggestions; to Esther Hart for her drawing of the adult; to Jean Boitchenko for his field collection of parasite material; and to Theodore Malama for his clerical assistance.

[2] Order Hymenoptera, family Braconidae.

[3] Italic numbers in parenthesis refer to Literature Cited, p. 26.

A single colony of what is thought to have been *A. thompsoni* was found by Thompson and Parker in corn in the Jura district of eastern France in 1921. In 1924 a more extended search for the parasite resulted in the discovery of several points in northern France, notably in the region of Lille, Nord, where it occurred as a parasite of the borer in Artemisia in sufficient abundance to permit its collection for shipment to the United States.

The first shipment in quantity was made in 1926 and has been followed by further shipments each year since that time. To date 159,355 individuals of *A. thompsoni* have been collected in northern

FIGURE 1.—Map of area in which *Apanteles thompsoni* occurs in greatest abundance, including the district in northern France from which collections of this parasite are sent to the United States. Colonies have been found in all towns indicated

France and shipped to the United States. Of this number 5,935 were sent in 1926, 33,175 in 1927, 96,789 in 1928, and 23,456 in 1929.

DISTRIBUTION AND HOST RELATIONS

The favored habitat of *A. thompsoni*, so far as it is known, appears to be the Sequanian (north) zone,[4] covering an area that extends, roughly, from Arras (fig. 1), in the upper part of France, north to the coast and east toward Antwerp and Brussels in Belgium. Practically no corn is grown in this area, but within a radius of a few miles of the city of Lille about 50 per cent of the plants of *Artemisia vulgaris* L. are commonly infested by *P. nubilalis*.

[4] The arrangement of the biogeographical zones used in the discussion of *A. thompsoni* corresponds to that followed by Thompson and Parker (*25*) and Parker, Vance, Smith, and Gamkrelidze (*16*). Physical and climatic characteristics form the basis for the separation of these areas. Briefly, the zones here mentioned are: The Sequanian (north), comprised of the lowlands of north-central France, including the region of Flanders; the Sequanian (south), in the basin of the Seine, with the exception of its more eastern parts, including the city of Paris and its environs; the Rhodanian, the region east of the upper Rhône in France and the valley itself as far south as Privas, Valence, and Digne; the Aquitainian, covering the southwestern corner of France, bounded on the south by the Pyrenees, on the north and northeast by the foothills of the central plateau, and extending westward to the Atlantic Ocean; and the Danaprisian, the mixed forest and steppe region of the Dnieper River in Russia.

A. thompsoni has been found, however, in several other districts where corn is the chief food of the borer. In 1921 a few specimens were collected in the Jura area of eastern France known as the Rhodanian zone; its presence in very limited quantities was discovered near Bayonne, France, in the maritime part of the Aquitainian zone in 1928. Borer larvae collected in 1928 from the Danaprisian zone in Russia were parasitized by a gregarious braconid which was probably *A. thompsoni;* and Kotlán (*10*) has recorded a borer parasite from Hungary which may be the same species.

Although at present *P. nubilalis* is the only known host of this species of Apanteles, there is no reason to suppose that under proper conditions it would not attack larvae of related species.

CLIMATE AND AGRICULTURE OF FAVORED HABITAT

The Sequanian (north) zone, considered the favored habitat of *A. thompsoni*, as pointed out by Thompson and Parker (*25*), has a transitional type of climate. The mean yearly temperature is about 50° F., and that of the winter is 35° to 37°. There is an average absolute minimum temperature of about 12° and an average absolute maximum of about 93°. The five months, December to April, inclusive, constitute the drier part of the year, whereas the period from May to October has a higher precipitation. June and October are the rainiest months, and February is the driest. The average annual rainfall for Lille is about 27 inches.

For the most part the area is one of mixed agriculture. The successful culture of corn is prevented by the low summer temperatures, and Artemisia, a weed common in waste areas and along the railway lines, provides the chief food supply of the larvae of *P. nubilalis*.

ECONOMIC IMPORTANCE OF APANTELES THOMPSONI

The average parasitism of Pyrausta larvae by *A. thompsoni* for different years from 1920 to 1929, inclusive, in its various zones of known distribution, is shown in Table 1. The parasitism in the Sequanian (north) zone, where the most extensive investigations have been made, dropped decidedly, from 22.9 per cent in 1924 to 2.9 per cent in 1925, and has since remained rather low.

TABLE 1.—*Parasitism of larvae of Pyrausta nubilalis by Apanteles thompsoni, by years, in different zones*

Zone	Year	Average parasitism	Host plant	Zone	Year	Average parasitism	Host plant
		Per cent				*Per cent*	
Sequanian (north)	1920	(1)	Artemisia.	Sequanian (south)	1924	−0.01	Artemisia.
	1924	22.9	Do.	Rhodanian	1921	−.01	Corn.
	1925	2.9	Do.		1925	1.1	Artemisia.
	1926	3.2	Do.		1925	.08	Corn.
	1927	6.6	Do.	Aquitainian	1927	−.01	Do.
	1928	2.5	Do.	Danaprisian	1928	6.3	Do.
	1929	.5	Do.				

[1] First found.

In the year of heaviest parasitism, i. e., 1924, a maximum of 42.6 per cent was found in a collection of 513 specimens of host larvae from Lille, and in the same year 16.3 per cent of a collection of 276 borers was parasitized in the vicinity of Brussels.

The degree of parasitism by Apanteles varies at different points in the Sequanian (north) zone, as shown by a survey made during the winter of 1928–29 and presented in Table 2. These data show that as high parasitism as 15 per cent occurred that year at Merville, but that the average for Lille, obtained from the examination of a large number of specimens, was only 2.8 per cent.

TABLE 2.—*Local variation in degree of parasitism of Pyrausta nubilalis larvae by Apanteles thompsoni in northern France, 1928*

Locality	Host specimens examined	Parasitism	Locality	Host specimens examined	Parasitism
	Number	*Per cent*		*Number*	*Per cent*
Lille	3,803	2.8	Armentières	188	3.7
Arras	201	2.5	Orchies	156	2.6
Hazebrouck	118	8.5	Valenciennes	258	1.6
Merville	100	15.0			
Bailleul	320	2.5	Total	5,144	
			Average		3.1

With the exception of the 6.3 per cent parasitism found in a lot of larvae from Russia in 1928, the parasitism by Apanteles in borers infesting corn has been very slight, and the greater supply of this parasite has been obtained from Pyrausta larvae inhabiting Artemisia. In central Europe the species is so rarely encountered as a parasite of the corn borer that it is a negligible factor of control.

Superficially *A. thompsoni* does not appear to have great importance as a factor in the control of the corn borer, but it is undoubtedly true that it plays a certain rôle in the preservation of a natural balance which, if upset by its elimination, might allow the reproductive rate of the borer to increase and permit it to become a more severe pest of marketable crops than it is now.

DESCRIPTIONS

ADULT

(Fig. 2)

The original description of the species by Lyle (*11*), based on a study of 11 females collected in Lille, Nord, France, is as follows:

♀. Black, shining; palpi pale; antennae beneath fusco-testaceous; clypeus and mandibles rufo-testaceous; belly at base testaceous; sides of abdominal segments 1 and 2 fusco-testaceous; legs testaceous, with hind coxae black or blackish, hind femora and tibiae slightly infuscated at tips, and hind tarsi more or less infuscated. Wings subhyaline, stigma pale fuscous, nervures paler but usually visible to the extreme margin of the wing.

Thorax: Mesothorax smooth, shining, feebly punctate; scutellum and metathorax smooth and shining. Legs with spurs on hind tibiae half as long as the metatarsus. Abdomen with first segment rather more than twice as long as its medial breadth, with sides parallel for half its length then narrowed to the almost truncate apex, smooth with some faint lateral striation; second

segment rather more than half as long as third with two oblique impressed lines converging forward and enclosing a triangular space, smooth and shining like the remaining segments. Terebra briefly exserted, barely surpassing the anus.

Length, 3 mm.; expanse, 5–6 mm.

The male is at present unknown.

FIGURE 2.—Adult female of *Apanteles thompsoni*. × 16

EGG

Length at oviposition, 0.17625 mm.; greatest width, 0.05625 mm. The ovarian or newly laid egg (fig. 3, A) of *A. thompsoni* is translucent white, quasicylindrical in form, broadly rounded at its

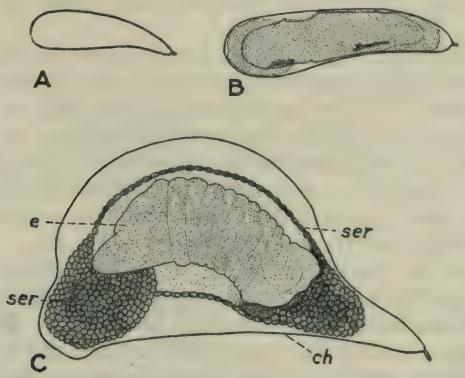

FIGURE 3.—Eggs of *Apanteles thompsoni*; A, Well-developed ovarian egg; B, egg 3 days old; C, egg 5 days old and just prior to hatching

cephalic end, and of nearly the same width for half of its length, after which it gently narrows to a smaller rounded caudal extremity which possesses a short blunt petiole. The surface is smooth.

Symbols used in Figures 3, 4, 5, 6, and 7

ac, anterior commissure.
av, anal vesicle.
br, brain.
ch, chorion.
cin, chitinous intima.
e, embryo.
epth, epithelium.
es, esophagus.
h, head.
hbg, histoblasts of external genital appendages.
hi, hind-intestine.
hrt, heart.
int, intestine.
lb, labium.
lbp, labial palpus.
lbr, labrum.
lbrpr, labral process.
lbse, labial seta.
md, mandible.
mi, mid-intestine.
mt, Malpighian tube.
mth, mouth.
mx, maxilla.
mxp, maxillary palpus.
mxse, maxillary seta.
r, rectum.
rov, rudimentary ovary.
s8, eighth abdominal segment.
s9, ninth abdominal segment.
ser, serosa.
sesgn, subesophageal ganglion.
slkd, common duct of silk glands.
slkdo, external opening of common duct of silk glands.
slkgl, silk glands.
sp, spiracle.
spo, spiracular opening.
vnc, ventral nerve cord.

FIRST-STAGE LARVA

Length on hatching, 0.64 mm.; near end of stage, 2 mm.; head width, 0.16 mm.; length of mandible, 0.0563 mm.

The larva (fig. 4, A) of *A. thompsoni*, upon hatching from the egg, has a translucent white body, fairly uniform in width but tapering very slightly from the head to the anal segment. The rather square head (*h*) is followed by three thoracic and seven distinct abdominal segments. The last abdominal segment is three times the length of any of the other segments, and might, perhaps, better be regarded as a division, since it, no doubt, represents several true but as yet undifferentiated segments. It carries at its extremity a slight cap-like swelling (*av*), which later further evaginates to form the anal vesicle.

Each of the last two thoracic and the seven abdominal segments bears dorsally a single transverse row of sharp, translucent spines directed posteriorly. These spines are nearly half as long as a segment, and the first eight rows are arranged across the middle of the segment; on the last and largest segment they are placed more anteriorly. Their number on any or all segments is variable, but commonly there are more present and they are less widely separated on the last three abdominal than on the other segments.

After a period of feeding and growth the larva (fig. 4, E), although still in the first stage, has changed considerably in appearance from that of its earliest condition just described. The body is now rather transparent, somewhat narrowed toward the head, and has at the anal extremity a large vesicle. In addition to the head there are now three thoracic and nine distinct abdominal segments, and an anal vesicle (*av*) which consists of an evagination of the hind-intestine. At this time the spines are so small in comparison with the increased size of the larva that they are seen with difficulty. The transparency of the cuticle and hypodermis, however, more easily permits a study of the internal anatomy of the larva.

The head (fig. 4, B, C) has a mouth opening (*mth*), located somewhat ventrally, with two sharp, slightly curved mandibles (C, *md;*

D). Both labrum (*lbr*) and labium (*lb*) are present, and from the top of the head a protuberance carrying two labral processes (B, C, *lbrpr*) projects over the mouth opening.

The 2-lobed brain (fig. 4, E, *br*) and subesophageal ganglion (*sesgn*) fill a large part of the head. The ventral nervous system (*vnc*) is continued by a chain of 13 ganglia, consisting of 1 ganglion in each of the three thoracic segments, 1 in each of the first seven abdominal segments, and 3, more or less fused, in the eighth and ninth abdominal segments. Main branches pass from the ganglia

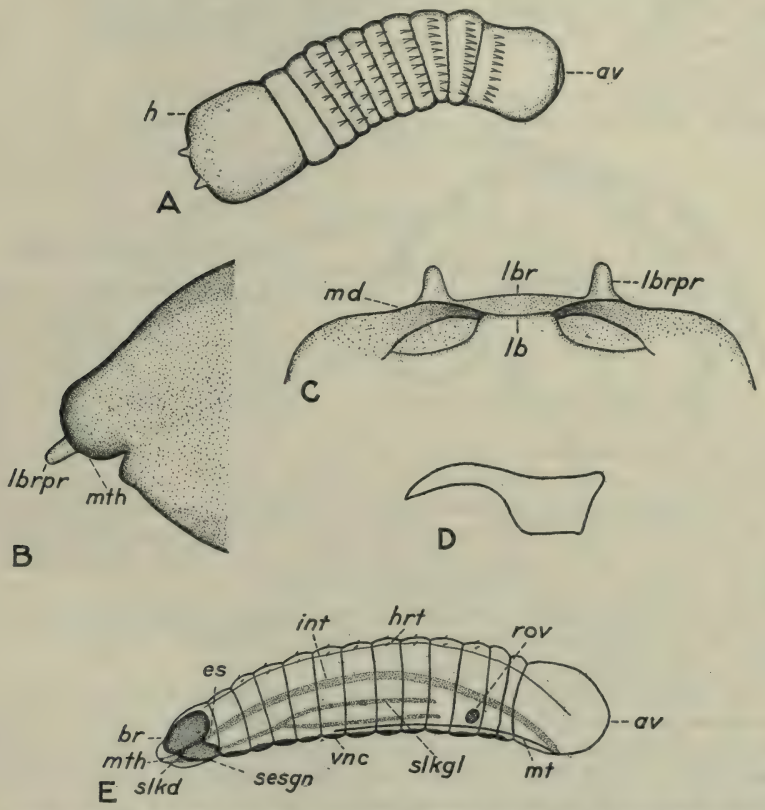

FIGURE 4.—First-stage larva of *Apanteles thompsoni:* A, Early first-stage larva, dorsal view; B, head of first-stage larva, lateral view; C, head of first-stage larva, viewed somewhat ventrally; D, mandible of first-stage larva; E, gross internal anatomy of late first-stage larva, lateral view, showing digestive tract, left Malpighian tube, ventral nervous system, heart, one of the silk glands, and one of the rudimentary ovaries

into the various segments and further distribute themselves to supply the entire body, with the exception of the anal vesicle, into which the nervous system does not extend.

Two fairly straight silk glands (*slkgl*) extend posteriorly and lateroventrally from the head region. These become bifurcated in the third thoracic segment—the branches of each ending abruptly in the region of the sixth abdominal segment. Just back of the mouth the two glands empty into a short common duct (*slkd*) which leads to the upper border of the labium.

From the mouth opening (*mth*) the digestive tract is continued by a slender esophagus (*es*) into the first thoracic segment, where it enlarges into the mid-intestine (*int*). This is a long, slightly curved tube lying near the center of the body and entering the anal vesicle, which it partially traverses. It ends on the ventral wall of this vesicle. At this point, and arising at the very apex of the mid-intestine, are attached two straight, slender Malpighian tubes (*mt*) which extend forward ventrally to the region of the second abdominal segment.

The heart (*hrt*) runs dorsally from the anterior segments to the anal vesicle; the posterior end situated within the vesicle is somewhat enlarged. The flow of blood, as usual, is controlled by a series of valves.

The tracheal system is present, but the very small tubes are not yet inflated with air. Situated in the region of the seventh abdominal segment and rather latero-ventrally are two rudimentary ovaries (*rov*).

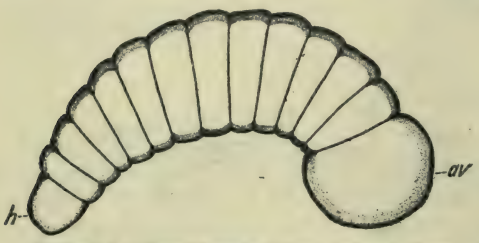

FIGURE 5.—Second-stage larva, lateral view

SECOND-STAGE LARVA

Length near end of stage, 4 mm.; width, 0.84 mm.; head width, 0.28 mm.

The larva (fig. 5) of this stage is somewhat club-shaped, being larger posteriorly and tapering toward the oblong head (*h*). The anal vesicle (*av*) is now as large or slightly larger in diameter than the widest abdominal segment, and the body segmentation is the same as in the fed larva of the previous stage. The larva has become more opaque and is of a creamy or yellowish color. Both mandibles and buccal armature are very slightly chitinized.

The tracheal system consists of two lateral longitudinal trunks, each of which gives rise to 10 principal branches; it appears to be filled with air but is still apneustic.

The mid-intestine is larger because of the feeding of the larva and the consequent accumulation of undigested material within the peritrophic membrane. Otherwise it differs little from that of the first-stage larva. The Malpighian tubes have increased in size and now extend to the first abdominal segment.

The silk glands, which have become larger and very much convoluted, fill the greater portion of the body cavity as far back as the seventh abdominal segment, and scattered fat cells are visible. The pear-shaped rudimentary ovaries are in the seventh abdominal segment, and the histoblasts of the external genital appendages (fig. 6, A) appear on the ventral floor of the eighth and ninth abdominal segments. The six imaginal buds of the legs show on the ventral surface of the three thoracic segments; laterally on the second and third thoracic segments are the developing wing pads.

LAST-STAGE LARVA

Length at end of feeding, 4.5 mm.; width, 1 mm.; head width, 0.48 mm.; length of mandibles, 0.08438 mm.; diameter of thoracic spiracular opening, 0.02437 mm.

In the earlier part of the last stage the shape of the Apanteles larva resembles that of the second stage; the anal vesicle persists and segmentation is the same. Later, at about the time of its issu-

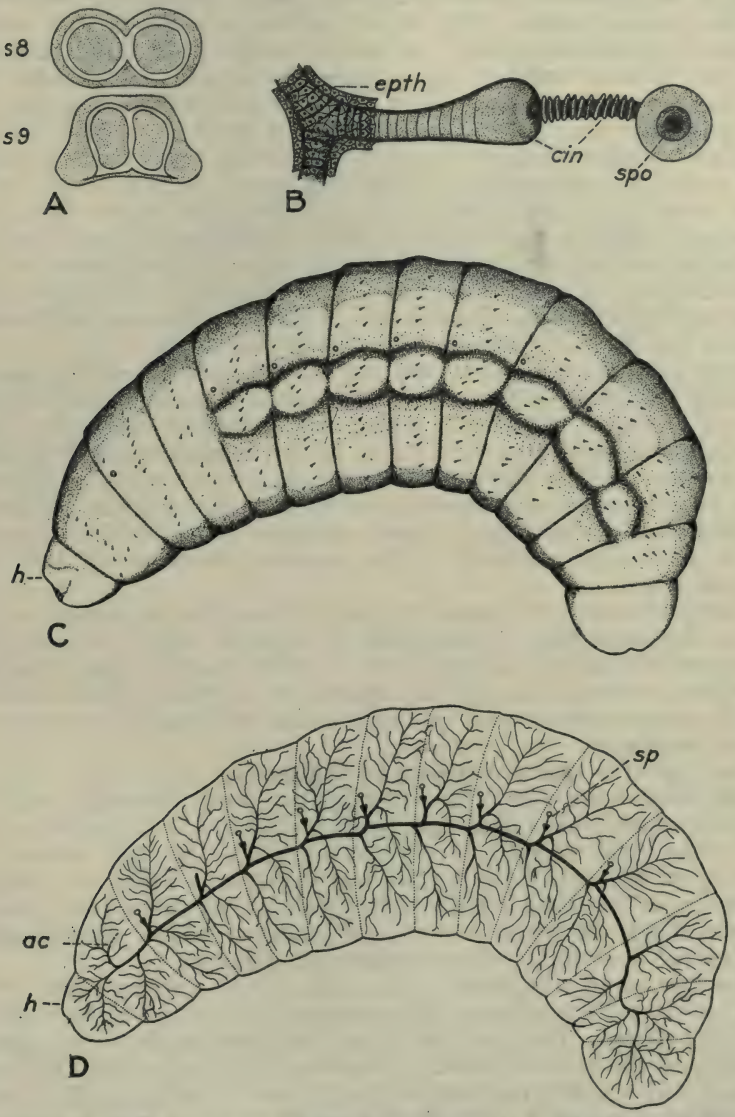

FIGURE 6.—Last-stage larva of *Apanteles thompsoni:* A, Histoblasts of external genital appendages located ventrally on the eighth and ninth abdominal segments of second-stage and last-stage larvae; B, thoracic spiracle and portion of trachea of last-stage larva, with part of epithelial layer cut away to show the chitinous intima; C, last-stage larva, lateral view; D, main tracheal system of last-stage larva, lateral view. (Only left half shown)

ance from the host, the parasite larva (fig. 6, C) assumes a more rounded and plump form, and the anal vesicle by invagination becomes the hind-intestine. The head and thoracic segments are now

supplemented by 10 well-differentiated abdominal segments, on the first 8 of which are rather large lateral lobes produced by the arrangement of the muscles in that part of the body. The larva is quite opaque, and urate cells are visibly distributed among the fat cells.

The tracheal system (fig. 6, D) is well developed and consists of two longitudinal trunks, one on each side of the body, united in the first thoracic segment by a transverse dorsal commissure (*ac*), but not joined posteriorly as in the case of certain ichneumonids, chalcids, and some other braconids. The head is supplied by two anterior branches from each longitudinal trunk, while the last abdominal segment is entered by the posterior end of the trunk, which there branches in all directions. From each main trunk a dorsal and a ventral branch are given off in each of the thoracic and first nine abdominal segments; these branches terminate in a network of fine ramifications. In addition, from near the base of these dorsal branches in the last two thoracic and first seven abdominal segments, a smaller branch leads inward in a ventral direction.

Open spiracles (fig. 6, D, *sp*) are present, one pair being located laterally and slightly dorsally in the second thoracic segment and in each of the first to seventh abdominal segments, inclusive. Each spiracular opening (fig. 6, B, *spo*) is surrounded by a light-brown chitinous ring. The chitinous intima (*cin*), surrounded by its single layer of epithelial cells (*epth*), runs inward for a short distance as a rather small spiral tube, but soon enlarges into a bulblike structure which gradually narrows to the general diameter of the main tracheal trunk.

The ventral nervous system, typical in general arrangement of that of the Hymenoptera, is composed of a brain (fig. 7, A, *br*), subesophageal ganglion (*sesgn*), and 11 other ganglia (*vnc*), the last of which occurs in the eighth abdominal segment. The two cords which connect the various ganglia, while not fused, are not very widely separated.

The digestive system consists of the mouth (fig. 7, A, *mth*), the slender esophagus (*es*), the mid-intestine (*mi*) distended with the contents of the peritrophic membrane and closed at its posterior end, the rather bulb shaped hind-intestine (*hi*), and the rectum (*r*) opening at the extremity of the last segment. From the anterior extremity of the hind-intestine two Malpighian tubes (*mt*) emerge, make a sharp downward curve, and continue rather straight along the ventral floor to the third abdominal segment.

The two large silk glands (fig. 7, A, *slkgl*) occupy much of the body cavity; their general arrangement is similar to that of the previous stages. The short common duct coming from the opening (*slkdo*) on the labium quickly branches into the two lateral glands, each of which subdivides in the third thoracic segment, after which the branches convolute for the remainder of their length in the abdominal segments.

The dorsal heart (fig. 7, A, *hrt*) is the chief organ of circulation, and by its valvular action causes the blood to flow and bathe the various internal organs.

The head (fig. 7, C) of the last-stage larva, with its well-chitinized and more distinctly outlined buccal parts, differs considerably in appearance from that of either previous stage. The lower edge of

the wide and somewhat raised labrum (*lbr*) extends back into the mouth opening (*mth*) in the form of a wide inverted V, in the apex of which are located four very minute, round, sensorial structures.

On each half of the upper lip are four short, closely placed, spinous sensory organs lying within a light-brown area, and immediately above are three short spines placed in a triangular form. Two more

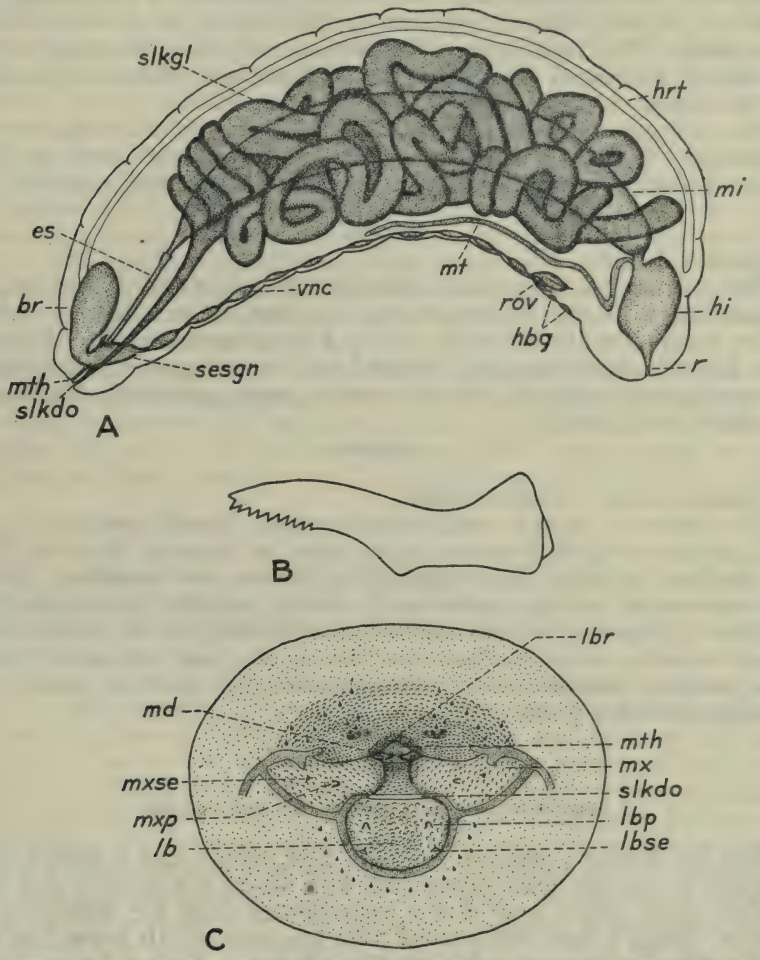

FIGURE 7.—Parts and organs of last-stage larva of *Apanteles thompsoni:* A, Gross internal anatomy of last-stage larva, lateral view, showing digestive system with left Malpighian tube, ventral nervous system, heart, one of the silk glands, and one of the rudimentary ovaries with histoblasts of external genital appendages; B, mandible of last-stage larva; C, head of last-stage larva, front view

such spines occur near the base of each mandible, and a row of five others extends from that region, but slightly nearer the mouth opening, in a direction upward and mediad.

Rather round in shape and slightly elevated, the labium (fig. 7, C, *lb*) bears near its lower edge a pair of widely separated setae (*lbse*), above which are situated the two labial palpi (*lbp*). Near its upper

margin occurs the slitlike opening (*slkdo*) of the common silk duct, beyond which the lip slopes into the mouth cavity.

The raised maxillae (fig. 7, C, *mx*) lie one on each side of the lower lip. Each bears a palpus (*mxp*) and a short seta (*mxse*), while about the lower edge of the labium on what may be termed the mentum 16 short spines are arranged in a semicircle.

Each of the two brownish and strongly chitinized mandibles (fig. 7, B and C, *md*) has a wide base, a short sharp point, and 10 sawlike teeth. The mandibles articulate on two short processes of the thickened epicranial suture, and the maxillae and labium are bounded by thickened chitinous borders.

The labrum, labium, and maxillae are covered with tiny round tubercles. These are most numerous on the labrum and on those parts of both labrum and labium bordering the mouth opening.

PUPA

Length, 3 mm.

The pupa of *A. thompsoni* is motionless and of the free or exarate type common to the Hymenoptera. At first it has a light-yellowish color, except for the blackish eyes and dark-brown ocelli. Within a few days the head and both ventral and dorsal parts of the thorax become smoky colored, and the entire pupa gradually darkens to the black of the adult.

COCOON

Length, 4 mm.; width, 1.5 mm.

The cocoon is woven with delicate white threads secreted by the silk glands of the full-grown larva after its issuance from the host. Its surface is dull. Both ends of the cocoon are rounded. All of the cocoons of a colony are loosely bound together in an irregular manner by similar threads and are also fastened to the inside of the plant tunnel or other surface upon which the host was resting when the parasite larvae issued. Occasionally the dead or dying host itself is included in the webwork.

BIOLOGY

BEHAVIOR UNDER LABORATORY CONDITIONS

For the writer's purpose, a box 2 feet square and 6 inches deep, covered at one end with cheesecloth and closed at the other end by a sliding glass plate, provided a satisfactory cage for handling the adults. Such a cage was placed with the cheesecloth toward a window and the opposite side partly opened. Young borer larvae (stages 1 to 4) to be parasitized were placed on the cage floor, and each one was removed after having been stung by the female. Quantitative handling and breeding of Apanteles, however, call for the use of a modification of such a cage to reduce the possibility of escape of the lively adults and so facilitate manipulation by the worker.

Immediately after being parasitized, the young borer larvae, in lots of 20 or 25, were put into small round tin boxes and supplied with leaves of dock for food. They were kept under such conditions at various temperatures until about their fourth instar, when each

was put into a glass vial and fed with stems of dock until the issuance and spinning of the mature parasite larvae. The colonies of parasite cocoons were then kept in similar vials and provided with slight moisture until the adults emerged.

Water and drops of sugar solution were constantly kept before the caged females, which fed on both fluids. Prolongation of the life of *A. thompsoni* seems to be best accomplished by the method used by Jones (*9*), i. e., keeping the adults in a box cage (similar to that just described) in a cool, dark closet and bringing them out into light and warmth for only a short time each day to allow them to feed and oviposit. Adults so treated lived as long as one month, whereas females placed in small glass globe cages, even when given food and moisture, lived only a few days.

Colonies of cocoons, if put in dry glass vials and kept at a constant temperature of either 68° or 77° F., almost invariably failed to produce adults, and subsequent dissection showed that death occurred at various points in the transformation of the pupa into the adult. The placing of moist blotting paper or a bit of green vegetable matter within the tube, as a rule, insured a satisfactory emergence. If too much moisture was provided, however, the results were sometimes unfavorable.

Temperature alone, during the development within the cocoon, seemed to be a less important factor, as equally high percentages of emergence were obtained under conditions of a constant temperature of either 68° or 77° F., and of ordinary room temperatures with a fluctutation from about 68° in the daytime to around 61° at night.

OVIPOSITION

Only a few seconds are required for the actual deposition of the eggs. Upon sensing the presence of a host larva the female quickly approaches and with one thrust of her ovipositor deposits a number of eggs in it.

She may oviposit two or three times in the same larva before leaving it to go through the more or less usual postoviposition motions of preening herself. The host larva is not paralyzed by the ovipositor of the female and continues to squirm constantly until the completion of oviposition. Oviposition may occur at any time of day.

The female assumes no characteristic position during the act of oviposition. At times the wings are held upright over the back and remain motionless, and often the clinging female is rolled completely over several times by the wriggling host larva. It was observed that the apparent inclination of the parasite to oviposit in a certain larva was sometimes more pronounced when two or more females were attacking it than when only one was present, and it was not uncommon to see several females in close contact and thrusting their ovipositors sharply at one another. In this connection it was noted that not all of the larvae punctured by the ovipositor of the female parasite actually contained eggs.

The number of eggs deposited at a single thrust of the ovipositor was variable. From 20 to 25 seems to be a normal number, although often more or fewer were found. Large numbers of eggs within a host, however, are usually the result of several depositions by one or several females. At one time the writer made an attempt to

"saturate" a large third-stage borer larva with Apanteles eggs. The larva was placed for 15 minutes in a cage containing many females, and according to close observation received 45 ovipositor thrusts. Upon dissection a total of 868 eggs were counted, or an average of 19 eggs per thrust, and no doubt the actual number of eggs deposited was even greater than could be determined by this count. The average capacity of the female ovaries seems to be about 230 eggs, although as many as 262 fairly well developed eggs were dissected from the ovaries of a female which had no opportunity to oviposit for several weeks.

The female will deposit eggs immediately after emergence, although the oviposition activities are considerably more pronounced after several days of feeding. It may be that in nature she first feeds and allows some time to pass before she begins a search for borer larvae.

There seems to be no decided preference on the part of the female as between second, third, and fourth stage larvae, and for oviposition purposes all three stages probably serve equally well. First and fifth stage larvae are not immune from attack, but the former are too small and weak in themselves to withstand parasitism effectively and soon die either from the shock of the sting or the presence of the parasite eggs, while the skin of the latter is too thick easily to permit the penetration of the ovipositor.

DEVELOPMENT OF THE EGG

At a constant temperature of 68° or 77° F. eggs within second, third, or fourth stage host larvae hatch in about five days. Under field conditions the incubation period is perhaps slightly longer.

Soon after deposition the egg begins to increase in size, and a steady growth, accompanied by slight changes in shape, is maintained until the time of hatching. The individual eggs from a single lot deposited at one time differ in the degree of development attained within the oviducts of the female, and a certain variation in the embryonic growth also occurs. The average daily development, however, as based upon a study of numerous entire and sectioned specimens, takes place about as described in the paragraphs that follow.

Cell differentiation soon commences, and on the first day after oviposition the entire preembryonic mass gradually pulls slightly away from the chorion at the posterior end of the egg.

The egg when 2 days old contains an outer layer of long columnar cells or blastoderm, within which lies a narrow longitudinal region filled with yolk matter and containing a number of yolk cells.

In the 3-day-old egg (fig. 3, B) are to be found the early embryonic layers in the process of formation and differentiation, surrounded by a cellular membrane. This envelope, the writer believes, is the serosa. A few cells are grouped at the two ends of the embryonic mass while the remaining cells form a narrow layer along its sides.

By the fourth day the embryo has formed, and the segments and larval organs are becoming defined. This embryo, composed of a large head and 10 other segments, lies in the center of the egg entirely surrounded by the cells of the serosa. The anterior half is

inclosed by a great mass of these round-shaped cells which extends out to the chorion, and a smaller quantity of the same type of cells is segregated at the posterior end. A single layer of the cells (more oval in form) extends lengthwise on both sides of the embryo to join the masses segregated at the anterior and posterior ends. Certain instances, however, have been observed in which a smaller quantity of serosal cells was present at either extremity of the embryo and more than one layer extended partly down the sides. Except where the serosal cells touch the very anterior inside of the chorion, the embryo inclosed within its cellular envelope lies free within the chorion of the egg, which is now considerably swollen but still retains more or less of its original shape.

The appearance of the egg (fig. 3, C) when 5 days old and just prior to hatching (bursting of the chorion) resembles in most respects that of the previous day as just described. It is greatly swollen dorsally and anteriorly, while the posterior portion of the chorion with its petiole is empty. Both the embryo (*e*) and the cells of the surrounding serosal envelope (*ser*) have increased in size, and the entire mass lies free in the expanded chorion. In fact the entire egg has so developed in size since its deposition that it is now three times the length of a fresh egg and eight times as wide through its middle. The embryo has attained its full growth, and shortly the chorion (*ch*) bursts, liberating a first-stage larva nearly surrounded by the clinging masses of serosal cells. The head parts, especially the labral processes, are the first to emerge from the cellular envelope. It is, however, several weeks before the first-stage larva has freed itself from these cells, and in some cases a few serosal cells have been found clinging to Apanteles larvae 1 month old. These cells distribute themselves throughout the body cavity of the host larva and are quite conspicuous when parasitized host larvae are dissected.

DISCUSSION OF THE EMBRYONIC ENVELOPE

Numerous references to the presence of a cellular envelope about the embryo of monembryonic entomophagous parasites have been published. Some authors, in speaking of the embryology of the parasitic Hymenoptera, term this envelope the amnion; others speak of it as the serosa; while those of a third group consider that both the amniotic and serosal layers are present. Recorded instances of the existence of very large quantities of serosal cells at the time of hatching of the egg, however, are less numerous, and many of these records, if not the larger part, appear to be confined to the Braconidae.

Tower (*27*) has figured diagrammatically the embryo of *Apanteles militaris* Walsh as surrounded first by the fused amniotic and serosal envelopes, later by these fused envelopes dividing into two parts, with the serosal cells grouped at each pole, and finally, at the time of hatching, by an amniotic layer inclosing the entire embryo and all within a thick layer of serosal cells extending out to the very chorion of the egg. He believed that there occurred a separation of the cells into one portion which is cast out at the poles of the egg and becomes a body of loose cells (of serosal origin) lying between the chorion and the embryo, and another portion which becomes a layer of broad flattened cells (amnion) inclosing the embryo.

Pemberton and Willard (*17*), in treating of the biology of several braconid fruit-fly parasites in Hawaii, speak of a "gelatinous mass of large cells" extending along the ventral surface of the body of the first-stage larva of *Diachasma tryoni* Cameron, from the back of the head to the tip of the abdomen, and state that these are the serosal cells which adhere to the larva until it molts for the first time. In making a comparison of *Opius humilis* Silv. with *D. tryoni*, these authors say that the ventral mass of serosal cells retained by *O. humilis* after the hatching of the larva is much smaller in volume, less conspicuous, and is often broken away from the larva before the molt to the second instar. The same authors also figure serosal cells still clinging to a cast skin of a first-instar larva of *Diachasma fullawayi* Silv. According to Willard (*28*), the larva of the braconid *Opius fletcheri* Silv. (a parasite of the melon fly), when first hatched, is surrounded by a mass of serosal cells which cling to it until it is almost ready to molt to the second instar. Willard states that these cells of *O. fletcheri*, however, were never observed clinging to the first larval molt as in the case of the three parasites of the Mediterranean fruit fly (*D. tryoni*, *O. humilis*, and *D. fullawayi*).

The egg of another braconid, *Dacnusa areolaris* Nees, is illustrated by Haviland (*6*) as containing a well-developed embryo surrounded by a "trophic membrane" which apparently consists of a large quantity of cells of serosal origin, polygonal in surface view, and resembling those present in the egg of *A. thompsoni*. This author states that toward the end of embryonic development the nuclei of these cells appear in various stages of degeneration. In an earlier paper Haviland (*5*) briefly considered the embryonic membrane in Charips, a member of the Cynipidae, and at the same time discussed the interpretations of Silvestri and Gatenby relative to such a membrane in certain of the Chalcididae.

Zorin (*30*), in a paper on *Apanteles gabrielis* Gaut. and Riel, has figured both the early and late stages of the egg of that species, showing the changes which take place in shape and size as the larval embryo develops. The egg of the later embryonic stages, as drawn by Zorin, appears to contain quantities of cells which are undoubtedly of serosal origin, although no explanation to this effect is offered. In fact the egg of *A. gabrielis* in all stages resembles very much that of *A. thompsoni*.

Grandori (*3*) mentions only the amnion as present in the egg of *Apanteles glomeratus* (L.) Reinh., and discusses the persistence of the cells of this envelope until the issuing of the internal-feeding parasite larvae from their host.

In a study of the parasites and hyperparasites of aphids Spencer (*24*) has given some interesting data on the serosa as it occurs in certain species of the Aphidiinae, a subfamily of the Braconidae. This author states that only a single embryonic membrane is formed by these species and that in the case of *Diaeretus rapae* Curt. it is derived from a delamination or extrusion of cells from the ectoderm of the early embryo. During embryonic development these cells increase in size and number, become polyhedral in shape with oval nuclei, and fit rather loosely around the embryo. There exists the probability, according to this writer, that the serosal membrane is broken up by a cytolytic enzyme secreted by the larva. At any rate, with the hatching of the larva the serosa divides into various-sized

fragments which undergo a strange process of vacuolization and growth and are finally devoured with the various tissues of the aphid.

More recently Jackson (*8*) has thrown new light on the serosal membrane and the way in which it functions in the braconid *Dinocampus* (*Perilitus*) *rutilus* Nees, and has summarized much of the previous work on this subject. Miss Jackson discovered that the cells of the embryonic membrane in *D. rutilus* increased in size with the development of the embryo until the hatching of the egg. They then became dissociated and dispersed throughout the body cavity of the host, where they grew in size by the absorption of fatty matters from the host until they became quite stretched out with fat globules, and in this condition they constituted the principal food of the parasite larva in its later stages. Death of the parasite larva did not affect the dissociation and subsequent development of the cells of the embryonic membrane. This writer believes that many workers have considered similar cells in parasitized larvae only as disorganized fat bodies of the host and have overlooked their true nature.

Among the Chalcididae the embryonic envelope has received the attention of several authors. Henneguy (*7*, *p. 337*), in speaking of the group of insects having a single embryonic envelope, illustrates the egg of *Smicra clavipes* and says that the cells of the membrane, after the hatching of the egg, become somewhat spherical in shape, absorb fat globules, and then degenerate in the body cavity of the host, where it is possible that they are later eaten by the parasite larvae.

An account of the embryonic membrane found in the Platygasters has been given by Marchal (*12*). Following the eclosion of the larva of *Trichacis remulus* Walker, the amnion breaks up into round or oval bodies to which this author has given the name "pseudogermes." The bodies grow and multiply for some time after they are free and floating about in the blood of the host larva. The dissociation of the embryonic envelope in *Platygaster lineatus* Kieffer and *P. marchali* Kieffer was found to be similar, but in the species *P. ornatus* Kieffer a "trophamnios" is present and a paranucleus undergoes multiple division to form a body which finally divides into irregular masses, some of which remain attached to the larva while others float free in the body cavity of the host as "pseudogermes."

In a new and interesting paper on the Sirex parasites Chrystal (*2*) speaks of the embryonic envelope in Ibalia as the trophic membrane or trophamnion and says that it is composed of various-sized cells possessing large nuclei. This writer found that the larva of *Ibalia leucospoides* Hochew. issued head-first from one end of the trophamnion and the ruptured cuticular envelope remained unchanged in appearance up until the third stage of the parasite. Up to that time no dissociation of the cells was observed and it seemed unlikely that any difference would be noted in the fourth or last stage larva. It, therefore, appeared probable that the cells either degenerated or disappeared just previous to the final destruction of the host larva or that they were devoured by the parasite.

The cellular envelope present in the egg of *Encyrtus aphidivorus* Mayr, and of *Oophthora semblidis* Aur., two species of Chalcididae,

is called the "pseudoserosa" by Silvestri (*22*), who considers it as differing in origin from the serosa of other insects.

LARVAL GROWTH AND PUPATION

The larva of *A. thompsoni*, so far as observed, is strictly an endoparasite which spends practically all of its life free within the body cavity of the host larva from whose substance its nourishment is derived.

According to the writer's observations the parasite passes through three distinct and well-defined larval stages, molting twice in the body of the host and a third time within the newly spun cocoon. The cast skins of the first and second molts are pushed back toward the posterior end of the larva, where they sometimes remain attached for a short time before being entirely shed.

The writer at one time observed the movements of several Apanteles in their efforts to issue from the host larva. Through the integument of the host could be seen the head of the parasite larva as it moved back and forth over a small area on the inside of the host's skin, and the chitinous head armature, aided by the sharp-toothed mandibles, scraped away the intervening hypodermis and other tissues. Finally the tip of one of the mandibles pierced the skin, and after several minutes of the same to-and-fro motion the mandibles gradually enlarged the hole until the head of the parasite larva could be pushed through. Forward muscular movements of the larva continued until it issued free from the host about 45 minutes later. There is a tendency for the parasite larvae to issue along the lateral line of the host larva.

An Apanteles larva often starts spinning while issuing from the host, and the threads are first attached near the middle of its own body. In about 8 hours it has inclosed itself within a fine network of white threads through which the head may be seen still moving about as more threads are spun and attached. Nearly 24 hours are required for the whole spinning process and another period of like duration elapses before the casting of the meconium and voiding of waste matter within the cocoon just prior to pupation. A few days after spinning it is easy to distinguish through the white texture of the cocoon the dark-colored cast meconium at the posterior end and the brown eyes of the developing pupa near the other end.

Observations made on Apanteles colonies kept under outdoor insectary conditions during the middle of May at Hyères, where the temperature averages higher than at Lille during the same period, showed the pupal period to vary between a minimum of 9 days and a maximum of 15, with 14 as an average. At a constant temperature of either 68° or 77° F. the pupal period was only 8 days, and at ordinary room temperature approaching those just mentioned, but fluctuating, little difference in length of time was noted.

In emerging from its cocoon the adult cuts a neat cap almost off from the cephalic end of the cocoon and emerges head first. The average colony of Apanteles consists of from 15 to 20 individuals. In one count of 37 colonies containing 864 individuals, based on dissections of host larvae, the average size of a colony was 23, with a maximum of 61 and a minimum of 9. Thompson and Parker (*25*) have recorded an average of 15 individuals per colony.

LIFE OF THE ADULT

The adult of *A. thompsoni* is a delicate insect and rather susceptible to meteorological conditions. It dies quickly if provided with too little or no food or if kept constantly at a temperature that is too high or where the relative humidity is too low. Regardless of temperature, death usually occurs within 24 hours after emergence unless the female is able to ingest moisture. Provided only with such moisture, the maximum longevity of females at a constant temperature of 77° F., or at a fluctuating room temperature, was only 2 days. At 64.4° the life of one individual given only water was prolonged for a period of 4 days. All of the above females were confined separately in small glass globe cages. One female remaining from a lot put into a large square box cage lived for 26 days at 64.4° when given moisture and sugar water, and others placed in box cages at the same temperature, similarly fed, and subjected to light and warmth for only a short time each day, lived several weeks.

Usually all of the adults of a single colony emerged within a few hours, and it was seldom that living adults remained in their cocoons longer than 24 hours after the start of emergence. In controlled experiments, at both a constant temperature of 77° F. and under ordinary heated-room conditions, the emergence was 83.7 per cent, at 68° it was 78.1 per cent, and in an outdoor insectary it was 76.5 per cent.

The adult of *A. thompsoni* is positively phototropic, but not as decidedly so as are many other hymenopterous parasites. When handled, the adults will often attempt to escape from the cage by flying or walking directly away from a source of strong light, and in this action they are sometimes very persistent.

EFFECT OF PARASITE ON HOST

Parasitized larvae of *P. nubilalis*, regardless of the stage in which they are attacked by *A. thompsoni*, grow and approach maturity. Within such borers the Apanteles larvae feed upon the substance of the host and at times possibly attack the vital organs. Such feeding has a weakening effect upon the host, and parasitized larvae containing nearly mature Apanteles larvae can often be distinguished from healthy specimens by their somewhat drawn appearance and the slowness of their movements. In the earliest stages of parasitism by Apanteles, however, such distinction is more difficult.

Death is the fate of any larva of *P. nubilalis* from which Apanteles have issued, and in no known instance has pupation of the host followed. The wounds caused by the exit of the parasite larvae soon close, and the Pyrausta larva may continue to move about sluggishly for days before death takes place. It is probable that the longevity of such a larva from which parasites have issued is dependent upon the number of parasite larvae which it has nourished and the severity of direct injury which has occurred to the more vital organs.

The average length of life of six host larvae after parasite issuance was 9 days at 77° F., with a maximum of 14 and a minimum of 4 days, while for six other larvae kept at a room temperature of about 68° the average longevity was 11 days, with a maximum of 19 and a

minimum of 4. One larva of *P. nubilalis*, at 68°, lived 25 days after the issuance of the parasite larvae.

SEASONAL HISTORY

A. thompsoni, after overwintering as a partly grown first-stage larva within the body of its host, continues development into the second and third stages in early spring, and issues to spin its cocoon from the middle of April to the end of the third week in May. The period of maximum spinning varies somewhat from year to year according to weather conditions, but in general this may be said to occur between May 7 and 21. Adults usually start emerging about May 15, and by June 4 nearly all have left their cocoons.

In the spring of 1925, in the vicinity of Brussels, Belgium, spun colonies were found in the field on May 2, and near Antwerp the first colony was observed on May 7. In 1926 a colony of Apanteles cocoons was found on April 22 in the region of Lille, France, and from 21 borer larvae (out of a collection of 323) parasite colonies had issued and spun on May 1. Records for 1928 indicate a somewhat earlier spinning and pupation of the parasite larvae, and in shipments from Lille to Hyères colonies had spun as early as April 16. Fresh colonies of cocoons were found from that date on until May 24.

The first colony of cocoons in 1929 was collected in the field in the Lille region on May 8, when approximately 10 per cent of the Apanteles colonies had issued from their hosts. On May 13 about 25 per cent had issued, and by May 23 practically 100 per cent had spun. Issuance from daily collections of Pyrausta larvae sent to Hyères and kept under outdoor insectary conditions covered a nearly parallel period from May 14 to 24.

Although the first empty Apanteles cocoons were not found in the field in 1929 until May 31, the emergence of adults, from the first colony of cocoons collected, had started by May 20. Laboratory data taken on the colonies under observation showed an emergence period lasting from May 22 to June 1, and it seems quite certain from later field collections that the majority of the adults had emerged by June 7.

All of the writer's data indicate the occurrence annually of only one full generation of *A. thompsoni* in northern France and Belgium. The females which emerge in late May and early June probably wait several weeks for the occurrence of Pyrausta larvae large enough to serve for oviposition. Just when egg laying by Apanteles commences or when the peak of oviposition is reached has not been determined.

Thompson and Parker (*25*) were of the opinion that Apanteles had two generations a year in the Lille region, from the fact that empty cocoons were found about the middle of August, 1925, in green Artemisia plants. However, several times in June and July, 1929, Apanteles cocoons from which the adults had emerged were collected from Artemisia of that year's growth, indicating that the overwintering host larvae sometimes migrate into the fresh Artemisia stems in the spring before the time for the parasite larvae to issue. It seems probable, therefore, that the first record was of this nature and that *A. thompsoni* really has but one generation a year.

Field collections of young borer larvae were made at frequent intervals during the summers of 1927 and 1929 in the region of Lille, and such larvae were later dissected. The data are summarized in Table 3. It should be mentioned that the collections, 611 larvae in 1927 and 767 in 1929, contained second, third, fourth, and fifth stage borers, but that only those which were found parasitized by *A. thompsoni* are listed in the table.

TABLE 3.—*Parasitism by Apanteles thompsoni in summer field collections of Pyrausta nubilalis at Lille, France, 1927 and 1929*

Year	Number of larvae collected [1]	Period of collection	Apanteles found			Percentage of parasitism
			Date	Stage of host larva	Stage of parasite larva	
1927	611	Aug. 10 to 30	Aug. 27	Fourth	First	3.9
			Aug. 29	do	do	3.3
			Aug. 30	do	do	2.4
1929	767	July 10 to Sept. 10	Sept. 6	Fifth	do	1.7

[1] Collections contained larvae of various stages as found in the field.

It seems peculiar that Apanteles, either in the egg or first larval stage, was not found in these collections of early-stage host larvae earlier than August 27 in 1927 or September 6 in 1929. Two possible explanations of this condition may be offered; (1) that the collections were too small and that borer larvae in the field contained early stages of Apanteles but by chance were not included in the collections; and (2) that Apanteles has a summer generation in an alternate host and does not attack Pyrausta larvae before the latter part of August. To the writer the first explanation seems the more plausible.

LIMITING FACTORS

It is difficult to explain why this parasite is not more widely dispersed in other similar and apparently favorable regions inhabited by the corn borer. In this respect the writer can only say that perhaps the various climatic factors operating to produce a certain synchronization between the seasonal rhythm of the host and parasite do not operate to produce the same results in other zones.

Drought and excessive heat would appear to be two factors which prevent a continuance of the species in the more southerly regions of western Europe. Its confinement to the Sequanian (north) zone and apparent absence in the Paris district are less easy to explain, however. It may be that the somewhat warmer climate of the latter with its less abundant rainfall is the responsible factor.

The foregoing explanation, while it may account for the geographical limits of this species, does not explain its numerical limits within the zone where it is found. Although the writer has never reared any hyperparasite from *A. thompsoni*, the fact that other members of this genus are often so attacked would indicate that this species is not immune. It does not seem probable, from dissections and observations, that superparasitism is a factor limiting the abundance of the species (although it does limit its efficiency).

On the other hand, counts made on colonies of cocoons sent in from the field during the summer of 1929 and after the period of normal emergence have shown that a certain mortality occurred among the parasites in the pupal or adult stages within the cocoons. As high as 25 per cent mortality has been found, and it may be that some factor, operating in the field to prevent a normal emergence of adults from the cocoons, limits the abundance of the insect in the zone considered as its optimum.

THELYOTOKY

Parthenogenesis, or the ability of a female to produce offspring without actual fertilization by a male of the species, is not uncommon in many groups of the animal kingdom and has often been mentioned in literature upon various hymenopterous parasites.

Many careful observers have shown that fertilized females of the Hymenoptera normally produce both males and females while unfertilized females are generally arrhenotokous and leave only male descendants or more rarely exhibit deuterotoky and give rise to progeny of both sexes. In every such case, however, so far as the writer has been able to learn, both sexes of the species in question are known to occur in reasonable abundance.

On the other hand, thelyotoky, in which only females are constantly produced and the opposite sex is either unknown or only rarely encountered, is much more unusual among the parasitic Hymenoptera. *A. thompsoni* is an example of this class in which the male is unknown, and parthenogenesis of the thelyotokous type may be regarded as a normal procedure in this species.

It is interesting to review different examples of thelyotoky already discovered among the three best-known families of the parasitic Hymenoptera. At the present time the family Chalcididae lead both the Ichneumonidae and Braconidae in the number of species recorded as reproducing in this manner, owing possibly to the more extended studies made upon the biology of the members of this group.

The offspring of *Thripoctenus russelli* Crawford, an internal chalcid parasite of Thysanoptera, according to the observations of Russell (*21*), were always females.

McConnell (*13*) has stated that unfertilized females of the chalcid *Eupelminus saltator* Lindm. are thelyotokous and that rearings from unmated females for as many as six generations always give female progeny. This characteristic of the species has been further corroborated by Phillips and Poos (*18*), as well as by Muesebeck and Dohanian (*14*).

Timberlake and Clausen (*26*) have reported *Achrysopophagus modestus* Timberlake as producing generation after generation of females without the intervention of the male, and add that reproduction of the species *Pseudleptomastix squammulata* Girault and *Anagyrus subalbicornis* (Girault) is "generally parthenogenetic," the male being found only occasionally and not in sufficient numbers to permit the general fertilization of the females.

Smith and Compere (*23*) believe that *Coccophagus modestus* Silv. is thelyotokous, the males only occasionally being found, and state

that such a condition is true in the case of certain other species of Coccophagus.

In a recent paper, part of which is devoted to the biology of *Aphelinus jucundus* Gahan, a primary parasite of the geranium aphid, Griswold (*4*) states that the male of this insect has never been described and concludes from various studies that the species is thelyotokous.

This form of parthenogenesis has been noted only a few times among the Ichneumonidae. Picard (*19*) mentions it in the case of *Hemiteles longicauda* Thoms. and remarks that "Les mâles doivent être très rares car je n'en ai pas obtenu en élevage et n'en ai pas rencontré dans la nature." He further observes that such parthenogenesis is very remarkable in the Ichneumonidae.

In their study of hyperparasitism Muesebeck and Dohanian (*14*) also found a species of Hemiteles which proved to be thelyotokous, the male being unknown, and they have employed this characteristic of *Hemiteles tenellus* Say to distinguish it from the European species *H. areator* (Panz.) which exhibits no difference in morphological characters.

The only other example of thelyotoky in the Ichneumonidae seems to be that of *Nemeritis canescens* Grav., mentioned by Picard (*20*) and later corroborated by Wojnovskaja-Krieger (*29*). Only females are produced by this species, and the male is unknown.

An even lesser number of references to agamogenesis in which only female progeny result is to be found in literature upon the Braconidae. Ogloblin (*15*), in speaking of *Dinocampus terminatus* Nees, says that "jusqu'à présent c'est le seul exemple connu de parthénogènèse thélyotoque dans la famille des Braconides"; and Balduf (*1*), in writing on the same species under the name of *D. coccinellae* Schrank, expresses the belief that the reproduction of this parasite is purely thelyotokous. No other instance seems to have been recorded until the present writing.

Thelyotoky is probably more common among the parasitic Hymenoptera than it is now supposed to be, and future investigations will no doubt reveal much interesting evidence upon the subject. Time may reveal the existence of the male, at least in rare occurrence, among those species in which it is now entirely unknown.

ECONOMIC IMPORTANCE OF THELYOTOKY IN THE HYMENOPTEROUS PARASITES

Certain authors, more notably Clausen (*26*), have discussed the economic value of thelyotoky among the parasitic Hymenoptera, and Clausen has attempted to show that frequent or general reproduction in this way results in a much greater rate of increase than would be the case if a portion of the progeny were males. To bear out this idea he has calculated that the possible increase for one year, allowing five generations of 50 each and no mortality, of *Achrysopophagus modestus* Timberlake, producing only females, would be at least four times as great as if fertilization had taken place and progeny of both sexes in the ratio of one to three had been produced.

As this writer states, no evidence has been given to show that the continued absence of the male contributes to a weakening of

the race, although in certain cases a reduction in the average number of the progeny because of lack of fertilization might offset any advantage otherwise obtained.

It is possible that a thelyotokous species of parasite has an economic advantage over an arrhenotokous or even a deuterotokous species, and by mathematical calculation, considering other factors as constant, one may readily reach this conclusion. However, in the case of *A. thompsoni* at least, it would seem that any such advantage, if not offset by other disadvantageous factors in the zone it inhabits, would manifest itself in a proportionately greater economic importance of the species in its particular habitat as compared with that of other coexistent species of parasites. But this does not seem to be the case, and it is necessary to conclude that if any such advantage really exists, it is utilized in maintaining the species at its present quantitative level; and conversely, without this advantage the species would be numerically less abundant. It therefore appears unlikely that any essential advantage of thelyotoky, unless of value in the native home of a parasite, would develop following its importation into a new environment.

It is true, of course, that in the breeding of a thelyotokous parasite in the laboratory for liberation in the field, much time and labor are saved because matings are unnecessary and the actual rearing and handling of the males is dispensed with. There is also one other point which may be favorable to a thelyotokous species, namely, that after liberation in a new environment, there will be no hindrance to, or even slowing up of, the reproduction of the parasite because of nonfertilization of the surviving females, which for some time may be limited in numbers and rather widely distributed.

METHODS OF QUANTITY COLLECTION AND SHIPMENT

Owing to the fact that *A. thompsoni* overwinters as a larva within the body of its host, it was found that the most feasible method of handling was to collect and ship the host borers during the winter months and allow the adult parasites to emerge the following spring.

Hired collectors of larvae of *P. nubilalis* usually work in the field in the vicinity of Lille from the middle of October until the end of March. Each worker carriers a round tin screen container in which pieces of folded paper have been placed. He dissects stems of dry standing Artemisia plants as he finds them in the field or by the wayside and places all Pyrausta larvae in the container where they soon crawl into the folds of the paper.

As the climate in northern France during the winter months is cold, the larvae when collected are very inactive. It is therefore necessary to put them in a warm place to increase activity so that they will crawl more readily into the holes in the strips of corrugated paper provided for them in the metal shipping can. The shipping can used, together with its contents of narrow upright strips of corrugated paper, is of the type designed by D. W. Jones, of the European corn-borer laboratory of the United States Bureau of Entomology at Arlington, Mass.

The larvae when placed in such a can readily enter the paper corrugations and inclose themselves by a compact silk web spun across

the openings, until the bundle of paper sections looks more or less like a honeycomb. Approximately 400 larvae are put into each can, and the cans of larvae so prepared are packed tightly in a wooden box for shipment to the United States.

SUMMARY

Apanteles thompsoni Lyle is a gregarious braconid found most abundantly in Europe in the environs of the city of Lille, France, where it occurs as an internal parasite of the larva of the European corn borer, *Pyrausta nubilalis* Hübn. In this area the parasite attacks Pyrausta larvae infesting the weed *Artemisia vulgaris* L. It has also been recorded from Artemisia in the Sequanian (south) zone, from both Artemisia and corn in the Rhodanian zone, and from corn in the Aquitainian and Danaprisian zones.

From the Sequanian (north) zone, in which the city of Lille is situated, winter shipments of the host larvae have been made to the United States by the Bureau of Entomology from 1926 to 1929, inclusive, and a total of 159,355 individuals of *A. thompsoni* have been reared from this material.

Collectors of the host larvae usually work in the field from the middle of October until the end of March. The larvae are cut out of dry Artemisia stems, packed in specially designed tin cans, and shipped in large lots to the United States, where emergence of the parasite is obtained the following spring.

The economic importance of this parasite of the corn borer in its natural habitat has varied from year to year, and its prevalence within restricted areas has differed considerably. The maximum parasitism recorded for the species is 42.6 per cent, found in a lot of borer larvae from Lille in 1924, with an average of 22.9 per cent for all collections made that year. Parasitism since that time has been much lower, the highest annual average in the 5-year period, 1925 to 1929, having been only 6.6 per cent.

The species, first described by G. T. Lyle in 1927, is thelyotokous, the male being entirely unknown. The female, with a single thrust of her ovipositor, usually deposits 20 to 25 eggs within the body cavity of the young Pyrausta larva. After about five days these eggs hatch into larvae which pass two full stages and the greater part of a third stage within the host, from whose substance nourishment is derived. When nearly full grown, the parasite larvae issue from the host and spin their cocoons. Emergence of the adults occurs about 14 days later.

The female is capable of depositing several hundred eggs and may oviposit more than once within the same host larva. The normal colony of Apanteles consists of from 15 to 20 individuals; a colony of 61 is the largest found in the course of dissections.

The host larva, from which Apanteles have issued, dies. Actual death, however, may not occur for a number of days or even several weeks after the issuance of the parasite larvae.

The developing embryo within the egg of Apanteles is surrounded by an envelope of serosal cells which often remains partly attached to the hatched larvae for several weeks. Other workers have noted similar embryonic envelopes among certain species of hymenopterous parasites.

Apanteles adults, if provided with proper moisture and food conditions, may be kept alive in the laboratory for several weeks, and oviposition in young Pyrausta larvae is easily obtained.

A. thompsoni overwinters as a partly grown first-stage larva within the body of the host. Development into the second and third stages begins in early spring, and the larva issues from the host to spin its cocoon from the middle of April to the middle of May. Adult emergence starts by the end of the second week in May and continues into early June. Present available data indicate the occurrence of only one generation annually in the Lille region.

Examples of thelyotoky among the Chalcididae have been recorded by numerous writers and more rarely mentioned by observers of the Ichneumonidae. The present bulletin records what is thought to be the second example of this form of parthenogenesis among braconid parasites.

LITERATURE CITED

(1) BALDUF, W. V.
1926. THE BIONOMICS OF DINOCAMPUS COCCINELLÆ SCHRANK. Ann. Ent. Soc. Amer. 19: 465–498, illus.

(2) CHRYSTAL, R. N.
1930. STUDIES OF THE SIREX PARASITES. Oxford Forestry Mem. 11, 63 p.

(3) GRANDORI, R.
1911. CONTRIBUTO ALL' EMBRIOLOGIA E ALLA BIOLOGIA DELL' APANTELES GLOMERATUS (L.) REINH. (IMENOTTERO PARASSITA DEL BRUCO DI PIERIS BRASSICAE L.). Redia 7 (fasc. 2): [363]–428, illus.

(4) GRISWOLD, G. H.
1929. ON THE BIONOMICS OF A PRIMARY PARASITE AND OF TWO HYPERPARASITES OF THE GERANIUM APHID. Ann. Ent. Soc. Amer. 22: 438–458, illus.

(5) HAVILAND, M. D.
1921. ON THE BIONOMICS AND POST-EMBRYONIC DEVELOPMENT OF CERTAIN CYNIPID HYPERPARASITES OF APHIDES. Quart. Jour. Micros. Sci. [London] 65 (pt. 3): [451]–478, illus.

(6) ———
1922. ON THE LARVAL DEVELOPMENT OF DACNUSA AREOLARIS NEES (BRACONIDAE), A PARASITE OF PHYTOMYZINAE (DIPTERA), WITH A NOTE ON CERTAIN CHALCID PARASITES OF PHYTOMYZIDS. Parasitology 14: 167–173, illus.

(7) HENNEGUY, L. F.
1904. LES INSECTES, MORPHOLOGIE—REPRODUCTION—EMBRYOGÉNIE. 804 p., illus. Paris.

(8) JACKSON, D. J.
1928. THE BIOLOGY OF DINOCAMPUS (PERILITUS) RUTILUS NEES, A BRACONID PARASITE OF SITONA LINEATA L.—PART I. Zool. Soc. London Proc. 1928 (pt. 2): 597–630.

(9) JONES, D. W.
1929. IMPORTED PARASITES OF THE EUROPEAN CORN BORER IN AMERICA. U. S. Dept. Agr. Tech. Bul. 98, 28 p., illus.

(10) KOTLÁN, A.
1928. A DOUBLE PARASITIC INFECTION OF A LARVA OF PYRAUSTA NUBILALIS HB. Internatl. Corn Borer Invest. Sci. Rpts. 1927–28: 174–178, illus.

(11) LYLE, G. T.
1927. TWO NEW SPECIES OF APANTELES (HYM., BRACONIDAE). Bul. Ent. Research 17 (pt. 4): 415–416.

(12) MARCHAL, P.
1906. RECHERCHES SUR LA BIOLOGIE ET LE DÉVELOPPEMENT DES HYMÉNOPTÈRES PARASITES. LES PLATYGASTERS. Arch. Zool. Expt. et Gen. (4) 4: [485]–640, illus.

(13) MCCONNELL, W. R.
1918. EUPELMINUS SALTATOR LINDM. AS A PARASITE OF THE HESSIAN FLY. Jour. Econ. Ent. 11: 168–175, illus.

(14) MUESEBECK, C. F. W., and DOHANIAN, S. M.
1927. A STUDY IN HYPERPARASITISM, WITH PARTICULAR REFERENCE TO THE PARASITES OF APANTELES MELANOSCELUS (RATZEBURG). U. S. Dept. Agr. Bul. 1487, 35 p., illus.

(15) OGLOBLIN, A.
1924. LE RÔLE DU BLASTODERME EXTRAEMBRYONNAIRE DU DINOCAMPUS TERMINATUS NEES PENDANT L'ÉTAT LARVAIRE. Pub. Inst. Zool. Univ. Charles de Prague, v. 2: 1–27, illus.

(16) PARKER, H. L., VANCE, A. M., SMITH, H. D., and GAMKRELIDZE, W.
1929. PYRAUSTA NUBILALIS HÜBN. IN EUROPE: NOTES ON INFESTATION AND PARASITISM FROM 1926 TO 1928. Jour. Econ. Ent. 22: 688–693.

(17) PEMBERTON, C. E., and WILLARD, H. F.
1918. A CONTRIBUTION TO THE BIOLOGY OF FRUIT-FLY PARASITES IN HAWAII. Jour. Agr. Research 15: 419–466, illus.

(18) PHILLIPS, W. J., and POOS, F. W.
1927. TWO HYMENOPTEROUS PARASITES OF AMERICAN JOINTWORMS. Jour. Agr. Research 34: 473–488, illus.

(19) PICARD, F.
1922. CONTRIBUTION À L'ÉTUDE DES PARASITES DE "PIERIS BRASSICAE" L. Bul. Biol. France et Belg. 56 (fasc. 1): [54]–130.

(20) ———
1923. RECHERCHES BIOLOGIQUES ET ANATOMIQUES SUR "MELITTOBIA ACASTA" WALK. (HYMÉNOPTÈRE CHALCIDIEN.) Bul. Biol. France et Belg. 57 (fasc. 4): [469]–508, illus.

(21) RUSSELL, H. M.
1912. AN INTERNAL PARASITE OF THYSANOPTERA. U. S. Dept. Agr., Bur. Ent. Tech. Ser. 23 (pt. 2): 25–52, illus.

(22) SILVESTRI, F.
1909. CONTRIBUZIONI ALLA CONOSCENZA BIOLOGICA DEGLI IMMENOTTERI PARASSITI. II. SVILUPPO DELL' AGENIASPIS FUSCICOLLIS (DALM.) E NOTE BIOGRAFÍCHE. Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 3: 29–85, illus.

(23) SMITH, H. S., and COMPERE, H.
1926. THE ESTABLISHMENT IN CALIFORNIA OF COCCOPHAGUS MODESTUS SILV. (APHELINIDAE, HYMENOPTERA), WITH NOTES ON ITS LIFE HISTORY. Calif. Univ. Pubs., Ent. 4(3): [51]–61, illus.

(24) SPENCER, H.
1926. BIOLOGY OF THE PARASITES AND HYPERPARASITES OF APHIDS. Ann. Ent. Soc. Amer. 19: 119–157, illus.

(25) THOMPSON, W. R., and PARKER, H. L.
1928. THE EUROPEAN CORN BORER AND ITS CONTROLLING FACTORS IN EUROPE. U. S. Dept. Agr. Tech. Bul. 59, 63 p., illus.

(26) TIMBERLAKE, P. H., and CLAUSEN, C. P.
1924. THE PARASITES OF PSEUDOCOCCUS MARITIMUS (EHRHORN) IN CALIFORNIA (HYMENOPTERA, CHALCIDOIDEA). PART I. TAXONOMIC STUDIES. (By P. H. Timberlake.) PART II. BIOLOGICAL STUDIES AND LIFE HISTORIES. (By C. P. Clausen.) Calif. Univ. Pubs. Ent. Tech. Bul., v. 3, no. 2, p. 223–292, illus.

(27) TOWER, D. G.
1915. BIOLOGY OF APANTELES MILITARIS. Jour. Agr. Research 5: 495–508, illus.

(28) WILLARD, H. F.
1920. OPIUS FLETCHERI AS A PARASITE OF THE MELON FLY IN HAWAII. Jour. Agr. Research 20: 423–438, illus.

(29) WOJNOVSKAJA-KRIEGER, T.
1927. ZUR BIOLOGIE VON NEMERITIS CANESCENS GRAV.—DES PARASITEN DER MEHLMOTTE EPHESTIA KÜHNIELLA ZELLER. Bur. Appl. Ent. Rpts. [Leningrad] 3: 24–35, illus. [In Russian. Summary in German, p. 34.]

(30) ZORIN, P.
1925. CONTRIBUTIONS À LA BIOLOGIE DE L'APANTELES GABRIELIS GAUT. ET RIEL. [In Russian.] La Défense des Plantes. Bul. Bur. Perm. Cong. Entomo-Phytopath. Russie 2 (3): 138–147, illus.

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MARKETING APPLES GROWN IN THE CUMBERLAND-SHENANDOAH REGION OF PENNSYLVANIA, VIRGINIA, AND WEST VIRGINIA

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In cooperation with the Virginia Agricultural and Mechanical College and Polytechnic Institute; College of Agriculture, West Virginia University; and School of Agriculture, Pennsylvania State College

CONTENTS

	Page
Introduction	1
Method of study and application of results	3
Market outlets	5
Where the apples go	6
Prices received at destination	7
Wholesale and retail outlets in Pennsylvania cities	12
Wholesale and retail outlets in Virginia and West Virginia cities	17
Heavy supplies add to marketing difficulties	20
Market supplies of some varieties to increase	23
Cold storage an aid to orderly marketing	26
Some varieties sell better than others	29
Prices differ in various parts of region	30
Prices of varieties influenced by time of sale	32
Varieties handled in local markets	34
Grade an important price factor	37
Marketing services and charges	40
Methods of sale	46
Containers	48
Summary	50

INTRODUCTION

Marketing of apples grown in the Cumberland-Shenandoah region is a matter of increasing concern to producers. Commercial production has increased greatly during recent years all over the country, and competition is keen. Production problems have not all been solved, especially some phases that affect the marketability of the fruit.

The Cumberland-Shenandoah region is for the most part well adapted to the production of apples, particularly of certain varieties.

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Its commercial production began to be important in the nineties and has increased greatly during the last 30 years. The orchards, with some outstanding exceptions, are developments from general grain and livestock farming; in the course of these developments all sorts of trials were made in the selection of sites for orchards and of varieties planted. Experience has proved that some of the orchards were placed on poor soils and in unfavorable locations. Such orchards persist; they yield some return to their owners in years of high prices, but in general they are not so profitable as the orchards set on good soils and on good sites.

Low yields obtained in many of the orchards and low quality of the fruit produced have had a discouraging effect on the producers, so that the finer points of successful orchard practice have not been widely adopted. Some owners feel they can not afford to put more money into their orchards, yet lack of sufficient attention to certain phases of production handicaps their efforts in selling fruit and results in lower prices than are obtained by some of the better growers.

The region can consume only a very small proportion of the apples grown, and must sell outside in the industrial and metropolitan centers. In domestic markets the apples of this region compete with those produced nearer the consuming centers, where the quality is about the same and transportation may be the factor that decides where the apples from the region are sold. The character of this competition has changed somewhat with the decline of farm orchards in the East and with the increase in commercial production all over the country.

An outlet for the fruit of this region was found in the European market in the early days, and this market has been developed. In some years 60 per cent of the commercial crop goes to Europe, mainly to England. The export market is the mainstay of these producers, but northwestern growers, pressed with the necessity of finding outlets for increasing supplies, have penetrated this foreign market with large quantities of high-grade fruit. This competition is especially keen in years of large domestic crops and is now menacing the strong position of the Cumberland-Shenandoah region that was built up in the early years of the apple-export trade.

The situation is understood in a general way, but in the present unorganized state of production and marketing in the region the relative influence of several of the common problems is not always clear. Natural conditions differ widely in this mountainous region, 250 miles long and perhaps 50 miles wide, which in some degree also affect the channels of distribution. There are hundreds of growers, large and small, some selling direct, others through various local dealers and itinerant buyers. A great many varieties are grown, which is a contributing factor to existing differences in the apples grown. These and other things constitute a complex problem, with many possible solutions. (Fig. 1.) Measurements of some of the factors were attempted through interviews with growers, dealers, storage operators, wholesalers, and retailers, whose experience is summarized in this bulletin.

METHOD OF STUDY AND APPLICATION OF RESULTS

The main body of data included in this bulletin consists of prices received by growers for fruit definitely described and were obtained from sales account records for more than 590,000 barrels of apples sold in three seasons—1924–25, 1925–26, and 1926–27. These detailed data were obtained from growers, dealers, and others in Virginia, West Virginia, and Pennsylvania. Special data for Maryland were not obtained, but available statistics of a general nature are included for Maryland. These Maryland data are similar to data from the other three States, except that apple production on the Eastern Shore of Maryland is of greater importance compared

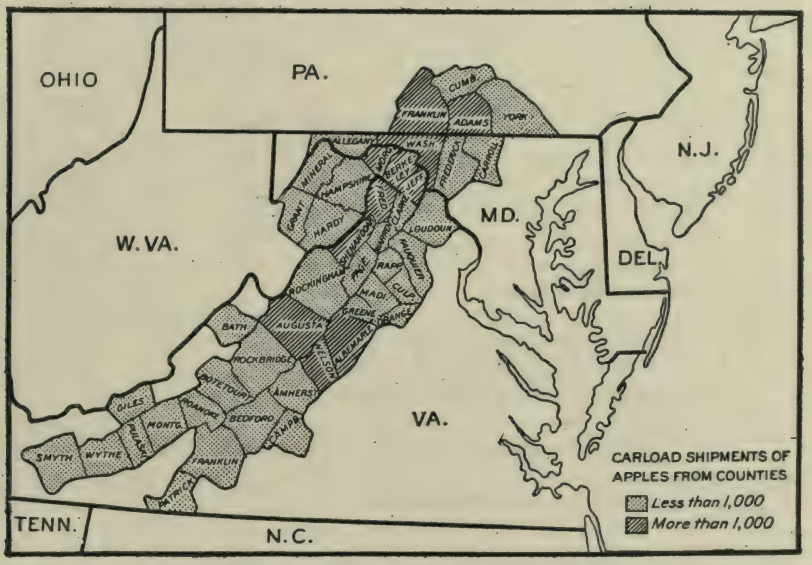

FIGURE 1. THE CUMBERLAND-SHENANDOAH APPLE REGION OF MARYLAND, PENNSYLVANIA, VIRGINIA, AND WEST VIRGINIA

Forty-five counties represent the principal apple-producing counties of the Cumberland-Shenandoah apple region

with the State total than is the production in the counties in the other States that are outside this region.

Local dealers and some of the grower-shippers made their sales records for these seasons available to the authors for analysis. Quantity, variety, primary destination, method of sale, time of sale, container, grade of fruit, and returns were stated in most cases. In general these data are felt to be typical of the business done, but they unavoidably lack complete proportional representativeness.

Part of the material presented refers to the region, and part refers to one or more of the Cumberland-Shenandoah States. For various reasons, each set of State material is not always presented in the same detail. For this reason and because growers in a particular State may have special interest in certain figures for their State,

the following outline for reference, listing, and paging the various materials, by States, is given:

Regional and State materials contained in this bulletin will be found on the pages indicated

Item	Regional	Pennsylvania	Virginia	West Virginia
Where the apples go:	*Pages*	*Pages*	*Pages*	*Pages*
Domestic and foreign distribution	6	7	6–7	7
Domestic and foreign prices to growers			7–9	9–11
Wholesale and retail outlets:				
Sources of supply of local cities		12–14	17–19	19
Channels through which apples were retailed		14–16		
Size of retail purchases		16		
Size of retail sales		20	20	20
Heavy supplies add to marketing difficulties:				
Decrease in number of trees owing to low prices	20–21			
Outlook for production in major apple regions	21–23			
Market supplies of some varieties to increase:				
Trends in plantings of designated varieties	23–25			
Sales of designated varieties, by sections of Virginia			25–26	
Cold storage an aid to orderly marketing:				
Cold-storage facilities in region	26	27	27	27
Quantity stored in 13 warehouses in Virginia			27	
Some varieties sell better than others:				
Prices received by growers for designated varieties	29–30	32	30–32	32
Volume of sales and relative importance of trees of designated varieties	29			
Prices received for designated varieties in domestic and foreign markets, by months			32–34	
Varieties handled in local markets:				
Supply of designated varieties received in carloads and by motor truck		34–37	34–37	
Grade an important price factor:				
Variations in quantities packed under different grades			37–39	39
Grades of York Imperial sold in domestic and in foreign markets			39	
Prices received for different grades of designated varieties			39–40	
Marketing services and charges:				
Services rendered by shippers	40–42			
Charges for handling apples			42	
Refrigeration and ocean and freight rates	43–45	43–45	43–45	43–45
Methods of sale:				
Methods used in the region	46–47			
F. o. b. and consignment sales and prices in domestic and foreign markets	47–48			
Containers:				
Volume of sales, by container			48–49	48–49
Prices received for apples in various containers			49	
Purchases by retailers, by type of container		49–50	49–50	49–50

It was obviously impossible to cover all the business of any considerable number of dealers, and the full detail desired was not always recorded on the books. York Imperial is known to dominate the trade, but it now seems likely that that variety has been somewhat overemphasized in the data obtained. Other varieties may have been sold in greater volume than the figures indicate. Still, as the trade feels that only a few varieties are produced in commercial volume, the business records made available by the dealers included in this study are probably sufficient to provide reasonably correct results for present purposes.

Wholesalers and retailers in small and large cities were interviewed with respect to preferences and practices with the idea that some of these might be of immediate significance to growers.

Cold storage of apples to extend the marketing period has developed in recent years. Available cold-storage space appears to be more than adequate in total but not always sufficient at a given point when the need is greatest. Storage-plant operators were interviewed and their replies summarized.

So it has been possible to show, besides the prices received for fruit, some of the facts and conditions to which price differences are thought to have been attributable. No involved statistical computations have been made. The prices and the reasons offered may therefore be readily checked and followed up in subsequent seasons. For the most part the facts are presented as observed during the period of study, without decision as to whether a practice was good or poor or the best possible under the circumstances. The nature of the practice may later be recognized and, if undesirable, may be changed.

MARKET OUTLETS

A consumer somewhere will take at some price an apple that is not badly decayed. Inspection of the bins and counters of city stores reveals fruit that is almost unbelievably unattractive. Yet some one will take the poorest fruit home for cooking if the price is low enough.

Fruit that is brought in from neighboring farm orchards without being packed, and often without being sorted, is essentially good enough in season to supply a large part of the low-price trade. Even windfalls, if of standard varieties, can be sold for culinary purposes in large quantities if a low price is asked. On our city markets the volume of poor fruit and fruit so ripe as to require immediate use is so large in years of large crops that fruit from a distance must be unusually good if it is to bring a return to the grower, after cost of packing, transportation to market, wholesale charges, and retail selling charges are deducted from the price consumers will pay for it.

The price concessions needed to move into consumption in city markets low-grade fruit and fruit that has gone out of condition are so great as to mean small returns to growers, if not actual loss. Retail dealers tend to handle only those kinds and grades of apples that their customers will take freely. Wholesalers have contacts with all sorts of retailers; the place the fruit received in the trade channels most likely to move it. Distributors find that certain varieties, grades, and packs move into consumption more freely than others, and they tend to confine their efforts to those apples and packs. With them interest centers on their profits, which are controlled by total money value of sales and expense of selling. Distributors protect their margins as long as they can, but often share with growers the burden of moving heavy crops into consumption. The price the grower gets is the price consumers will pay minus the cost of putting the fruit into the consumer's hands.

A given net price may result from vastly different services performed in the selling of apples, the consumer paying the difference. On the other hand, apples of the same description may bring a grower quite different net prices, because of market sought and of market conditions.

Apples are so firmly established in the dietary that there is now a much more even consumption than production throughout the season. Storage is a practical necessity, relieving the fall markets and supplying the late winter and spring trade. Some varieties can be held in common storage for several months, but increasing use is made of cold storage. Results indicate that prompt storage is better

than storage after transit to market, but the means of determining the details of an effective storage campaign have not yet been developed.

WHERE THE APPLES GO

Shipments in car lots were reported from 105 counties in the four States for the 1926 crop. Forty-five counties close together and essentially a unit region furnished 94 per cent of the car-lot shipments. Fewer counties (87) shipped cars of the 1924 crop, but 91 per cent of the movement came from the 45 counties which comprise the Cumberland-Shenandoah region.

Maryland orchards have contributed about 7 per cent of the car-lot movement reported for the four States. Nearly two-thirds of the Maryland movement originated in Allegany and Washington Counties, which are definitely included territorially in the region.

Availability of large stocks of apples within convenient distance from headquarters established in the area of greatest production has attracted dealers and representatives of foreign buyers in large numbers. Upwards of 200 dealers are resident in the region during the season, and itinerant buyers appear at times; moreover, some of the heaviest producers have enough fruit to enable them to sell on their own account.

Thus apples go from the region North, East, South, and West and to foreign countries. Export agents obtain considerable fruit each year, and take large quantities when domestic prices are low.

Apples from the four States were distributed to more than 400 markets in eastern United States and Canada. All told, these States supplied 19 per cent of the total car movement of the 1924 crop and were especially important sources of supply for Washington, Baltimore, and Philadelphia. Supplying 57, 28, and 31 per cent, respectively, of the car-lot supplies of these cities in 1924. Ten per cent of New York City unloads were from the four States.

The receipts (car-lot unloads) of apples of the 1926 crop at 46 markets are recorded in the Federal-State market news service bulletins by State of origin. The 46 markets accounted for 22 per cent of Pennsylvania car-lot shipments, 17 per cent of West Virginia, and 18 per cent of Virginia shipments. One hundred or more cars each were sent to three cities from Pennsylvania to 3 from West Virginia, and to 8 from Virginia. Of the 46 cities most obtained cars from each of the States.

Richmond, which is an important storage and distributing center, was the largest primary domestic outlet for Virginia apples of the 1926 crop, taking 752 cars, followed by New York with 599. New York took 243 cars from West Virginia, and two other cities took more than 100 each. New York and Philadelphia together took more than half the apples from the four States unloaded at 34 markets. Unload records for previous years are not available to the same extent. Considerable seasonal variation was noted in the direction of movement and proportional distribution of the domestic and the export trade.

The sales records of dealers and growers show the scope and character of the distribution of apples during three seasons. The total crop of 1924 was rather small, and only 22 per cent of the observed sales of Virginia apples went direct to foreign countries, as

compared with 45 per cent of the crop of 1925 and 64 per cent of the crop of 1926, the last-named year being one of heavy production in all sections of the United States. Direct shipments to the United Kingdom were 9 per cent, 24 per cent, and 35 per cent, respectively. Southern markets, including Virginia cities, took the largest part of the domestic sales reported. (Table 1.) Apples were shipped North, East, and West as far as St. Louis and Minneapolis.

TABLE 1.—*Proportional distribution of Virginia and West Virginia apples* [1] *sold by reporting dealers and growers in 1924–1926*

Origin and destination	Crop of 1924	Crop of 1925	Crop of 1926
Virginia apples sold in—	*Per cent*	*Per cent*	*Per cent*
Northeastern markets	16.5	8.6	7.7
Northwestern markets	13.8	1.5	4.2
Southern markets	40.1	39.2	21.9
Not specified	7.8	5.7	1.8
Total domestic	78.2	55.0	35.6
United Kingdom direct	9.3	23.6	35.0
Other European billings	12.5	20.6	26.0
South America		.8	3.4
Total foreign	21.8	45.0	64.4
West Virginia apples sold in—			
Northeastern markets [2]	47.46	43.40	68.57
Northwestern markets	15.56	7.34	11.19
Southern markets	36.98	49.26	20.24
Total	100.00	100.00	100.00

[1] 4 varieties constituted more than 90 per cent of the barrels sold.
[2] Includes all apples exported through the port of New York.

West Virginia apples go south and northwestward in domestic trade. Most of those reported as going to the Northeast (Table 1) were billed to New York and are believed to have been exported.

Pennsylvania growers depend less upon foreign trade and have developed near-by markets for a larger proportion of their production than have the other sections.

Rather striking differences in placement of varieties in the various general markets are shown in Table 2. The total quantities of some of the varieties are so small that a few sales, perhaps only one, cover the record for the variety as handled by the dealers reporting. No attempt is made to generalize from these sales except to draw attention to the importance of the widest contacts and of study of the market outlets. These sales reflect the activities and necessities of the selling agents; and another set might report quite different results, yet there are well-known market preferences for certain varieties. Wherever distinct variety preferences have developed, other varieties are variously discounted.

PRICES RECEIVED AT DESTINATION

Prices received by Virginia growers for apples of 10 of the principal varieties sold in the several general markets through dealers reporting sales show in a general way characteristic differences between the outlets. (Table 3.) The number of sales is so limited that full coverage of the field can not be presented here, and any given price is

subject to the effect of factors other than usual descriptions of fruit shipped to the indicated outlet. Yellow Newtown, for example, can usually be disposed of in domestic markets at comparatively high net prices. The reporting dealers sold few apples of this variety in the foreign trade in the first two seasons, but in 1926–27, 57 per cent of the Yellow Newtown apples handled by these dealers were consigned to the United Kingdom; these apples returned growers $3 per barrel, the lowest price for the variety but higher than was received for any other variety except Jonathan, which is a popular variety in Great Britain if it arrives in good condition.

TABLE 2.—*Proportional distribution of specified varieties in reported sales of Virginia apples by Virginia operators, crops of 1924–1926*

Variety	Crop of 1924			Crop of 1925			Crop of 1926		
	Northern	Southern	Foreign [1]	Northern	Southern	Foreign [2]	Northern	Southern	Foreign [3]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Arkansas (Mammoth Black Twig)	39.1	58.3	2.6	------	96.4	3.6	9.8	50.9	39.3
Baldwin	56.2	37.1	6.7	------	------	100.0	------	38.0	62.0
Ben Davis	38.1	37.9	24.0	------	------	100.0	6.6	3.7	89.7
Ben Hur	------	100.0	------	------	------	------	------	------	100.0
Black Ben	------	3.9	96.1	------	------	100.0	------	17.7	82.3
Bonum	------	------	------	------	------	100.0	------	------	100.0
Collins	------	------	------	------	99.1	.9	------	------	100.0
Delicious	83.9	16.0	.1	------	100.0	------	43.7	33.6	22.7
Early Harvest	------	100.0	------	------	------	------	------	------	------
Fallawater	------	------	------	------	------	------	------	------	100.0
Gano	------	91.9	8.1	------	39.1	60.9	------	3.1	96.9
Grimes Golden	18.8	80.9	.3	------	99.2	.8	10.7	51.4	37.9
Jonathan	5.5	3.2	91.3	------	14.3	85.7	6.0	13.8	80.2
King David	2.1	5.5	92.4	------	------	100.0	------	1.6	98.4
Lowry	44.8	55.2	------	------	100.0	------	.6	73.6	25.8
McIntosh	------	------	------	------	------	------	------	------	100.0
Maiden Blush	24.2	75.8	------	------	------	------	------	100.0	------
Nansemond	------	------	------	------	------	100.0	------	------	100.0
Northern Spy	100.0	------	------	------	------	------	------	------	100.0
Northwestern Greening	68.0	------	32.0	99.4	------	.6	51.9	------	48.1
Oldenburg (Duchess)	------	------	------	100.0	------	------	100.0	------	------
Rambo	100.0	------	------	------	------	------	------	------	100.0
Rome Beauty	52.6	------	47.4	23.5	75.7	.8	70.7	.2	29.1
Smokehouse	------	------	------	------	------	------	------	------	100.0
Springdale	------	------	------	------	------	------	------	------	100.0
Stayman Winesap	40.0	51.8	8.2	3.6	93.0	3.4	28.4	44.8	26.8
Virginia Beauty	100.0	------	------	------	------	------	------	------	100.0
Williams	------	------	------	------	------	------	100.0	------	------
Winesap	39.8	59.8	.4	14.7	71.5	13.8	20.4	48.5	31.1
Winter Paradise	53.8	5.5	40.7	------	100.0	------	27.4	------	72.6
Wolf River	------	100.0	------	------	100.0	------	------	100.0	------
Yellow Newtown (Albemarle Pippin)	68.3	30.6	1.1	55.2	44.2	.6	13.2	30.0	56.8
Yellow Transparent	30.7	69.3	------	------	100.0	------	100.0	------	------
York Imperial	31.1	44.8	24.1	12.1	41.8	46.1	11.5	15.7	72.8
All reported	38.0	50.4	11.6	13.8	53.0	33.2	15.7	28.4	55.9

[1] All sent direct to ports of the United Kingdom.

[2] All sent to United Kingdom, except Winesap 9.4 per cent to South America.

[3] All sent to United Kingdom except 10.8 per cent, as follows: 0.6 per cent to Norway, Sweden, and Denmark, distributed as follows: Arkansas, 0.1 per cent; Ben Davis, 1 per cent; Springdale, 29.8 per cent; Stayman Winesap, 0.3 per cent; Winesap, 1.6 per cent; York Imperial 0.4 per cent. To Germany and Holland 5.7 per cent as follows: Arkansas, 16.9 per cent; Black Ben, 20.1 per cent; Ben Davis, 13.5 per cent; Gano, 0.3 per cent; Springdale, 70.2 per cent; Stayman Winesap, 3 per cent; Winesap, 2.6 per cent; York Imperial 6.4 per cent. To South America 4.5 per cent, as follows: Ben Davis, 27.9 per cent; Bonum, 76 per cent; Delicious 10.5 per cent; Gano, 30 per cent; Jonathan, 13.4 per cent; King David, 16.8 per cent; York Imperial, 0.2 per cent.

TABLE 3.—*Prices per barrel net to Virginia growers received for No. 1 grade apples in all sizes, 2¼ inches and up, inclusive, packed in barrels, by geographical destination in different years*

Crop	Destination	Arkansas (Mammoth Black Twig)	Ben Davis	Delicious	Grimes Golden	Jonathan	Rome Beauty	Stayman Winesap	Winesap	York Imperial	Yellow Newtown (Albemarle Pippin)
1924	Northeastern markets	$3.66	$2.96	------	$4.50	$4.36	------	$4.36	$4.06	$3.63	$6.80
	Northwestern markets	2.63	------	------	2.81	4.00	------	3.90	4.46	3.47	------
	Southern markets	4.37	3.10	------	3.60	5.11	------	4.48	4.25	3.47	4.56
	United Kingdom	------	------	------	------	------	------	------	------	3.09	------
1925	Northeastern markets	------	------	------	------	------	$4.89	4.85	5.35	1.81	5.21
	Northwestern markets	------	------	------	------	------	------	------	4.09	3.38	------
	Southern markets	3.86	------	$4.09	3.66	------	4.47	4.19	4.89	3.48	5.22
	United Kingdom	------	------	------	------	------	------	------	------	3.31	------
	South America	------	------	------	------	------	------	------	5.41	------	------
1926	Northeastern markets	------	2.42	3.54	2.91	1.99	2.22	2.03	3.18	1.97	5.27
	Northwestern markets	2.27	------	3.57	2.29	1.58	3.15	1.80	2.86	2.30	3.69
	Southern markets	2.46	2.00	3.50	2.67	2.90	------	2.18	3.05	2.31	3.67
	United Kingdom	1.26	1.62	1.92	1.42	4.81	2.36	1.60	1.77	2.09	3.00
	Norway, Sweden, and Denmark	------	------	------	------	------	------	------	2.40	2.72	------
	Germany, Netherlands	2.47	2.68	------	------	------	------	1.83	1.51	2.39	------
	South America	------	2.61	3.16	------	3.37	------	------	------	------	------

In general, prices received by the growers for apples of the 10 varieties, other than Jonathan and Yellow Newtown, sold in the United Kingdom were somewhat lower than for those sold in domestic markets. Apples sold in the other foreign markets shown in Table 3 frequently brought better prices than were received in the United Kingdom. A number of the varieties listed in this table sold for relatively high prices in the southern markets of the United States.

The figures in Table 3, on which these statements are based, represent prices net to growers for specified varieties of apples described as to grade, but not described as to size, condition of fruit and pack, and time of sale. Consequently, they reflect what actually happened, but they do not reflect price differences that were caused by differences in products and time of sale.

In general, European markets prefer the smaller sizes of American apples. Size preference varies in different European markets, but the 2¼-inch minimum pack of barreled apples appears to be most readily taken, and anything larger than the 2¾-inch pack meets with a comparatively limited demand. However, the European consumer expects to find a goodly number of the larger apples in the 2¼-inch minimum pack and looks with disfavor upon the pack that contains a large proportion of apples of minimum size.

Apples shipped to foreign markets frequently arrive in poor condition, owing to scald, overripeness, and immaturity. Slack pack, overfaced pack, poorly sized fruit, and improper packing and handling have their influence on returns to the grower. Even so, the indications are that the Liverpool market for 2¼-inch minimum York Imperial and Ben Davis apples is generally as good an outlet as are domestic outlets. In some years Liverpool returns the grower more money than he gets through domestic f. o. b. sales. (Table 4.) Available figures for Winesap (Table 4) indicate that at no time up to November 12, do they return growers as much money when sold in Liverpool as they do when sold f. o. b. Martinsburg. Comparative figures are not available for Winesaps sold during the winter and spring months.

TABLE 4.—*Comparative returns per barrel to grower for specified varieties of apples sold f. o. b. Martinsburg, W. Va., and at the Liverpool, England, auction, United States No. 1, 2¼-inch minimum, 1925–1929* [1]

YORK IMPERIAL

Date of sale, 1927, and corresponding days in other years	Wednesdays, 1927, and corresponding days in other years	1925		1926		1927		1928		1929	
		Martinsburg	Liverpool	Martinsburg	Liverpool	Martinsburg	Liverpool	Martinsburg	Liverpool	Martinsburg	Liverpool
At Martinsburg:	At Liverpool:	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Sept. 5–10	Sept. 21	3. 90–4. 00	2. 76–3. 56				4. 13–4. 59				
Sept. 12–17	Sept. 28	3. 25–3. 65	2. 30–2. 76		4. 25–4. 59		5. 05–5. 96				
Sept. 19–24	Oct. 5	3. 50–3. 75	3. 10–4. 02		2. 53–3. 90	4. 00	6. 42–6. 88				
Sept. 26–Oct. 1	Oct. 12	2. 50–2. 75	3. 90–4. 48		2. 47–3. 68	3. 75–4. 25	6. 19–6. 88			3. 80–4. 00	4. 59–5. 05
Oct. 3–8	Oct. 19	3. 15–3. 25	4. 36–5. 05		3. 22–3. 68	4. 00–4. 50	4. 59–5. 05	3. 25–3. 30	2. 76–2. 99		3. 90–5. 28
Oct. 10–15	Oct. 26	3. 10–3. 75	3. 68–4. 36	2. 50–2. 60	2. 30–3. 45	4. 25–4. 35	4. 59–5. 05	3. 25–3. 45	2. 76–2. 99		3. 90–4. 36
Oct. 17–22	Nov. 2	3. 25–3. 75	3. 79–4. 25		1. 87–2. 53	4. 50	4. 13–4. 71	3. 00–3. 50	2. 99–3. 22	3. 90–4. 25	3. 79–4. 71
Oct. 24–29	Nov. 9	3. 50–3. 75	4. 13–4. 82	2. 50	2. 30–2. 53	4. 50–4. 65	3. 90–4. 36	3. 35	3. 45–4. 02	4. 00–4. 25	3. 45–3. 90
Oct. 31–Nov. 5	Nov. 16	3. 00	4. 13–4. 59		1. 96–2. 30	4. 00–4. 50	4. 36–4. 93	3. 00–3. 35	3. 33–4. 71	4. 00	2. 76–3. 22
Nov. 7–12	Nov. 23		4. 48–5. 05	2. 50	1. 38–1. 96	4. 00	4. 48–5. 05				
Nov. 14–19	Nov. 30			2. 50–2. 60	1. 62–2. 52		4. 36–4. 59				3. 22–3. 68

WINESAP

At Martinsburg:	At Liverpool:										
Sept. 12–17	Sept. 28										
Sept. 19–24	Oct. 5										
Sept. 26–Oct. 1	Oct. 12	4. 75–5. 00	2. 95–4. 36								5. 28–5. 51
Oct. 3–8	Oct. 19				3. 56–4. 36			4. 00			5. 96–6. 19
Oct. 10–Oct. 15	Oct. 26	4. 50–5. 00	3. 90–4. 00	3. 35	2. 76–3. 22	6. 00		4. 00	2. 55–2. 99		5. 73–6. 19
Oct. 17–22	Nov. 2	5. 00		3. 00–3. 25	2. 19–2. 45	6. 00	5. 05–5. 62	3. 20–4. 00	2. 55–2. 99	6. 00	4. 02–4. 48
Oct. 24–29	Nov. 9	5. 00	3. 68–4. 12	3. 00	2. 08–2. 30	6. 00–6. 25	5. 05–5. 62	4. 00	2. 55–3. 22	6. 00	3. 90–4. 36
Oct. 31–Nov. 5	Nov. 16			3. 00	1. 85–2. 08		4. 95–5. 16	4. 00–4. 25	2. 60–3. 22		3. 68–4. 13
Nov. 7–12	Nov. 23			3. 25	1. 85–2. 08		4. 36–5. 96		2. 99–3. 68		

At Martinsburg:	At Liverpool:										
Sept. 19–24	Oct. 5				3.22	4.50	5.57–5.62		2.99–3.22		3.20–3.79
Sept. 26–Oct. 1	Oct. 12		3.90–4.35	2.60–2.75	4.82	4.50	5.51–5.62	3.00	3.22–3.33	4.25	4.13–4.59
Oct. 3–8	Oct. 19		3.90–4.35	2.50–2.60	2.53–2.76	4.45–4.50	4.59–5.05	3.25	2.08–2.30		
Oct. 10–15	Oct. 26	3.25	2.76–3.90	2.30–2.50	2.08–2.30		4.02–4.59	3.25	1.85–2.08		3.68–4.02
Oct. 17–22	Nov. 2	3.25	2.76–3.56	2.40	1.62–1.85	4.50	3.45–3.79	3.25	1.73–1.90		2.76–3.45
Oct. 24–29	Nov. 9		2.42–3.43	2.40–2.50	1.73–2.08	4.00	3.45–3.68	3.00–3.25	1.85–2.30		2.60–3.10
Oct. 31–Nov. 5	Nov. 16			2.50–2.60	1.96–2.08		5.33–5.84	3.25–3.45	2.50–2.53		1.85–2.30

[1] F. o. b. prices at Martinsburg are weekly ranges taken from the daily market news reports of the Division of Fruits and Vegetables, Bureau of Agricultural Economics. Returns to growers for apples sold in Liverpool are the Wednesday auction sale prices in Liverpool converted to an f. o. b. basis at Martinsburg, by deducting all shipping and marketing costs. The returns to growers for f. o. b. sales and for Liverpool sales are arranged above so that the weekly range at Martinsburg can be compared with the auction range at Liverpool approximately 2 weeks later, the 2 weeks' lapse of time being approximate shipping time.

WHOLESALE AND RETAIL OUTLETS IN PENNSYLVANIA CITIES

In seeking wide and profitable distribution for the apples they have to sell, growers and dealers feel the effects of market preferences for varieties and packs through the attitudes of the wholesalers and retailers to whom they sell. The experience gained makes subsequent sales easier, provided a selection of outlets for the fruit in hand is possible. Retailers and wholesalers in 17 cities of Pennsylvania supplied figures and opinions with respect to their trade in apples. The figures apply to the situation in 1926–27; the comment is more general. A less detailed study of local marketing of apples was made in Virginia and West Virginia cities.

Every city of Pennsylvania is within hauling distance of farms on which apples are grown, and the "home market" is sufficient to absorb all the apples grown locally. Yet about half the counties regularly make rail shipments in car lots, and millions of bushels of apples are shipped in. Ninety per cent of the car-lot movement of Pennsylvania apples originated in four counties. Some of these cars moved out of the State, and cars from other States moved in.

Two of the 17 cities visited, Chambersburg and York, lie within the region under discussion. The entire supply for Chambersburg stores, excepting a few western apples, was purchased by the retailers direct from the farmers. The stores in York handled only a few western apples (5 per cent of sales); they purchased half their supply direct from farmers and the other half from dealers, but, so far as reported, sales in York of eastern fruit were of Pennsylvania-grown fruit, largely from York County. It appeared that growers around York had made considerable progress in getting consumers of that city to take their fruit first.

Philadelphia and Pittsburgh, on the other hand, depend on rail shipments for supplies, and they draw on all regions. The proportion of western apples sold is about half the total for Philadelphia and one-third the total for Pittsburgh. These cities are storage centers and distributing points from which surrounding communities are served.

The other cities have local sources of supply which are supplemented by rail receipts and by split cars and by supplies trucked in from other points.

The estimated total consumption of these 17 cities is nearly as great as the usual production of apples in Pennsylvania. The State as a whole takes several times as many apples as are produced within its borders; yet thousands of bushels are shipped out of the State each year.

In 1926–27, in spite of the large crop, the low prices, and the pressure to dispose of local stocks, these 17 cities took about one-third of their total supplies from Western States, judging from the reports of keepers of 820 retail stores. (Table 5.) Of the eastern apples sold by these stores, perhaps one-third were bought from farmers direct, one-third from Pennsylvania growers through the agency of wholesalers and dealers, and one-third from other Eastern States through the same agencies.

TABLE 5.—*Sale of apples by 820 retail stores in 17 Pennsylvania cities, 1926–27*

City	Stores	Apples sold			Purchased from farmers	
		Total	Eastern			
	Number	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent* [1]
Chambersburg	11	2,989	2,961	99	2,961	100
Coatesville	13	10,670	4,316	40	2,946	68
Connellsville	11	15,271	10,125	66	1,345	13
Dubois	10	3,820	2,265	59	242	11
Erie	59	37,637	34,089	91	8,498	25
Harrisburg	57	24,517	21,183	86	16,520	78
Huntingdon	6	977	732	75	732	100
Johnstown	42	22,626	19,129	85	16,458	86
New Castle	26	26,205	20,398	78	12,741	62
Philadelphia	323	176,058	87,038	49	13,240	15
Pittsburgh	112	87,689	55,320	63	2,055	4
Reading	29	21,463	16,054	75	12,871	80
Scranton	46	15,304	12,558	82	9,057	72
Shamokin	15	4,351	3,695	85	2,221	60
Washington	17	8,224	3,034	37	1,777	59
Williamsport	13	6,420	4,524	70	2,741	61
York	30	23,475	22,236	95	10,952	49
Total	820	487,696	319,657	66	117,357	37

[1] In terms of sales of eastern apples.

A general willingness to buy from farmers is indicated by the figures, but that willingness does not extend to preferment over more desirable varieties, grades, and condition. City dealers can sell apples as long as the fruit remains attractive to consumers, but more than ordinary care is necessary on the part of growers and handlers if varieties are to be in salable condition beyond their natural season. It has long been possible to have fresh apples every day in the year. Just how profitable it may be for growers to see to it that consumers generally eat apples in quantity the year around is still to be worked out.

Sources of supply by rail are shown in a general way by Tables 6 and 7. Thus 12 cities received 487 cars of apples of the 1926 crop. Pennsylvania supplied 21 per cent of these cars, the four States of the region supplied 46 per cent, New York 22 per cent, and the Pacific Coast States 28 per cent. Chambersburg, Huntingdon, and York received no cars in that season. (Table 6.) With the smaller cities accessibility seems to be the main factor in determining the regions from which supplies will normally be drawn. Western apples supplement the supply of eastern apples in quality, quantity, and season.

TABLE 6.—*Car-lot receipts of apples at 12 Pennsylvania cities, by origin, 1926* [1]

City	Total	Pennsylvania	West Virginia	Virginia	Maryland	New York	Other eastern	Pacific coast
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
Coatesville	5					5		
Connellsville	32		26			6		
Dubois	58		9			14	2	33
Erie	59					24	14	21
Harrisburg	18	13		1				4
Johnstown	67	12	37			7	4	7
New Castle	7					5		2
Reading	17	4				8		5
Scranton	142	54		25	6	14	1	42
Shamokin	30	3	16			4		7
Washington	20					10		10
Williamsport	32	16				10	2	4
Total	487	102	88	26	6	107	23	135

[1] Chambersburg, Harrisburg, and York received no cars in 1926–27.

TABLE 7.—*Source of car-lot unloads at Philadelphia and Pittsburgh, calendar years 1925–1927*

Year	Philadelphia							
	Pennsylvania		West Virginia, Virginia, and Maryland		Other		Total	
	Cars	*Per cent*	*Cars*	*Per cent*	*Cars*	*Per cent*	*Cars*	*Per cent*
1925	215	9	471	19	1,824	72	2,510	100
1926	307	12	470	18	1,845	70	2,622	100
1927	345	22	231	14	1,010	64	1,586	100

Year	Pittsburgh							
	Pennsylvania		West Virginia, Virginia, and Maryland		Other		Total	
	Cars	*Per cent*	*Cars*	*Per cent*	*Cars*	*Per cent*	*Cars*	*Per cent*
1925	88	3	226	9	2,256	88	2,570	100
1926	106	4	260	10	2,262	86	2,628	100
1927	244	11	696	33	1,187	56	2,127	100

Annual differences in rail movement to cities may be large, as indicated by the figures for Philadelphia and Pittsburgh. As these cities are large consuming centers they are the objectives of salesmen from all regions. Less difference in totals than in details is noticeable. (Table 7.)

Cities not large enough to absorb a whole carload of apples at a time can usually obtain sufficient supplies from other centers. Wholesalers in 13 of the cities visited reported receiving various quantities of fruit by motor truck and less-than-carload rail shipments. Of this small-lot business, 82 per cent was of Pennsylvania fruit, 9 per cent was of other eastern fruit, and 9 per cent was of western boxed apples. Wholesalers serving Connellsville and Huntingdon reported no truck or less-than-carload receipts.

Both Philadelphia and Pittsburgh are distributors as well as receivers. Even small cities, however, may take carloads for distribution to retailers in surrounding towns. Of 53 wholesale dealers operating from 14 of the cities other than Philadelphia and Pittsburgh, two-thirds reported distribution of apples to other towns in 1926–27, covering a distance as great as 75 miles. Boxed apples were sold outside in more instances than were barrels, and only a few dealers sold basket packs outside the headquarters city.

These 53 dealers depended on the individual retailer and chain-store retailer for most of their trade. A few took care of the hotel and restaurant trade, and others took care of the peddlers and fruit stands. Through small-lot sales retailers are encouraged to keep the fruit on display when it is freshest and most attractive; repeated handling soon renders good fruit unsalable.

Wholesalers in 14 cities reported the proportion of their sales which went to retailers of different types (Table 8) and the usual size of purchase. Most of the sales were made to retailers in lots ranging from 1 box or basket to 25 bushels; the usual sale was not larger than 5 packages. Chain stores bought from 7 of the wholesalers. Twelve wholesalers sold to restaurants, 12 sold to hotels, 25 sold to fruit

stores, and 28 sold to peddlers. For the most part the usual size of sale is a few packages, depending on the size of the retailer's business or the quantity needed for use in the course of a week. Retailers and consumers are not inclined to buy supplies for more than a few days ahead.

TABLE 8.—*Retail outlets of 53 wholesalers in 14 Pennsylvania cities in 1926*

City and dealer No.	Percentage of total sales of apples made through—							Trade area (radius)
	Jobber	Retail grocery store	Chain store	Restaurant	Hotel	Fruit store	Peddler	
Chambersburg:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Miles*
1		100						
Coatesville:								
2		100						50
3		33				34	33	10
Connellsville:								
4		80		5	5	10		
5		60				20	20	
Dubois:								
6		100						
7		100						
8		60	40					
Erie:								
9	10	75			5	5	5	
10		50		10		35	5	35
11	30	60				10		35
12	10	65	10	[1]	5	5	3	35
Harrisburg:								
13	20	10		10	10	40	10	40–50
14	20	50				10	20	25
15	60			20	20			
16	10	90						25
17		95		4		1		
Johnstown:								
21		50	5	5		10	30	30
22		75			8	8	9	30
23		75				25		30
New Castle:								
24		60				40		
25		35	20			30	15	15
26		10		2	8	80		
27		70		2	2	26		
Reading:								
28		90				10		
29		70				10	20	
30		40				60		
31		40	10				50	
32		40					60	
33		40		10	10	30	10	
34		70	15				15	6
Scranton:								
35								
36		60					40	20
37		50	5				[1] 45	
38		25					75	40
39		75					25	
40		25					75	
41	10	40					50	
Shamokin:								
42				10	15	75		8
43		50				50		
44		100						40
Washington:								
45		85				10	5	
Williamsport:								
46 [2]	5	35			5		30	60
47		95					5	25
48		90			10			50
49		80					20	15
York:								
50		75		15			10	15–20
51							100	
52 [3]	60							
53 [4]		10				5	5	

[1] Fruit stands buy boxes chiefly.
[2] 25 per cent sold direct to consumer.
[3] 40 per cent sold direct to consumer.
[4] 80 per cent sold direct to consumer.

The interviewed wholesalers stated that packages smaller than those now customary would not be popular, though a few suggested a smaller size than the bushel basket as worth experimenting with. Baskets were preferred by three-quarters of those interviewed. The small number who preferred boxes as containers were handling more western apples than the others and stated a preference for western apples as compared with local or other eastern-grown apples. The replies to questions regarding preferred sources of apples indicate that an advantage is held by near-by growers on the most convenient lines of transportation, with western apples supplementing their stocks with respect to quality, condition, and season. Four out of five reporting considered local fruit inferior to shipped-in fruit in grade and pack, but the number and location of those who said that local apples were equal or superior to the shipped-in fruit give basis for expectation that this position might be reversed if local growers made an earnest attempt to dominate the market that is inherently theirs. Four out of five said that it is hard to sell varieties other than the eight principal varieties; as between the principal varieties, 20 of the 53 wholesalers expressed no choice, whereas the other 33 named Baldwin, Stayman Winesap, and Winesap as preferred.

The usual size of retailer's purchase is less than 5 bushels, according to answers made by 500 retailers interviewed. (Table 9.) Four times as many retailers buy 3 barrels or fewer as buy 4 to 6 barrels. Only a very large business or a chain of stores can handle readily 25 or more bushels at a time, but here again accessibility of wholesaler has much to do with size of purchase; there is no need to carry heavy supplies in the store if the wholesaler can deliver frequently.

TABLE 9.—*Number of retailers in 17 Pennsylvania cities who usually buy their apples in lots of specified size, 1926–27*

City	Under 5 bushels	5–9 bushels	10–14 bushels	15–24 bushels	25 bushels and over [1]
Chambersburg	4	4	2	1	1
Coatesville	5	2	3		3
Connellsville	3	1		1	2
Dubois	6	2			
Erie	8	3	1	2	3
Harrisburg	20	10	3		8
Huntingdon	5	1			
Johnstown	11	9	1	3	2
New Castle	6	5	4	3	4
Philadelphia	42	32	17	20	38
Pittsburgh	22	21	13	6	10
Reading	7	6	1	2	5
Scranton	23	4	5	6	4
Shamokin	7	2		1	4
Washington	7	1		3	2
Williamsport	1	4	1	2	2
York	16		2	1	8
Total	193	107	53	51	96

[1] Nineteen large retail agencies regularly took a carload at a time.

Of nearly 488,000 bushels of apples purchased in 1926–27 by 820 retail stores in 17 Pennsylvania cities, 24 per cent were purchased direct from growers. (Table 10.) In some of the cities situated in the apple country, 50 per cent or more of the apples taken by the retailers interviewed were bought direct from the growers. In the

two large cities of Philadelphia and Pittsburgh, only 7.5 and 2.3 per cent, respectively, were purchased direct from the growers.

TABLE 10.—*Seasonal distribution of retail sales, and direct purchases from growers, by 820 retail stores in 17 Pennsylvania cities, 1926–27*

City	Sales					Bought direct from farmers	Percentage of eastern apples sold by retailers that were purchased from farmers			
	Total	Summer (July–August)	Fall (September–November)	Winter (December–March)	Spring (April–June)		Summer (July–August)	Fall (September–November)	Winter (December–March)	Spring (April–June)
	Bushels	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Bushels*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Chambersburg	2,989	12	27	35	26	2,961	100	100	100	100
Coatesville	10,670	16	32	41	11	2,946	40	53	100	100
Connellsville	15,271	9	29	38	24	1,345	13	12	16	11
Dubois	3,820	7	39	38	16	242	2	9	15	13
Erie	37,637	1	39	50	10	8,498	89	26	20	41
Harrisburg	24,517	12	27	37	24	16,520	76	82	76	78
Huntingdon	977	12	41	34	13	732	100	100	100	100
Johnstown	22,626	12	40	41	7	16,458	93	82	93	42
New Castle	26,205	6	32	41	21	12,741	55	73	69	33
Philadelphia	176,058	11	30	45	14	13,240	27	15	9	17
Pittsburgh	87,689	11	35	42	12	2,055	7	5	1	0
Reading	21,463	10	29	44	17	12,871	63	83	83	81
Scranton	15,304	8	32	42	18	9,057	56	76	74	66
Shamokin	4,351	9	31	44	16	2,221	85	60	63	42
Washington	8,224	11	31	38	20	1,777	43	71	92	0
Williamsport	6,420	7	37	45	11	2,741	54	58	65	55
York	23,475	14	34	33	19	10,952	54	59	39	45
Total	487,696					117,357				

WHOLESALE AND RETAIL OUTLETS IN VIRGINIA AND WEST VIRGINIA CITIES

Study of city markets in Virginia indicated much the same practices and points of view as were brought out in the study of city markets in Pennsylvania. If anything, the growers of the Cumberland-Shenandoah region have a greater advantage in Virginia markets than they have in the Pennsylvania markets. The eight cities visited for detailed study (Bristol, Danville, Lynchburg, Norfolk, Richmond, Roanoke, Staunton, and Petersburg) are distributing points for large areas as well as large consumers of apples on their own account. Absence of local production in significant quantities outside the region and convenience of trade routes make the Virginia sections of the region the natural source of supply.

Of the quantities received by rail at eight large cities of Virginia, only 7.5 per cent were western apples brought in to supply special trade. Norfolk draws more largely on States outside the region for its eastern apples than do the other cities.

The leading varieties that are received in carload lots in the Virginia cities considered are the Winesap, Stayman Winesap, and York Imperial, in the order given; these three constituted 30, 20, and 10 per cent, respectively, or 60 per cent of all the shipments received. The eastern growers should have no trouble, because of the varieties they produce, in satisfying the Virginia markets, for the varieties received in the largest quantities were almost entirely varieties that are popular in the Cumberland-Shenandoah region and can be grown to advantage.

Winesap, York Imperial, Yellow Newtown, and Stayman Winesap form 44, 10, 7, and 5 per cent, respectively, of the total quantity received by the eight Virginia cities in truck, wagon, or less-than-carlot rail shipments.

City dealers almost universally expressed a preference for such varieties of apples as are of dessert quality. Some included in their preferences a few varieties for cooking purposes. Such varieties as Winesap, Stayman Winesap, Delicious, Yellow Newtown, and Grimes Golden were most frequently cited in preferences by dealers in Virginia cities.

The preferences and practices of wholesalers reflect their ideas of the demand for apples and their opinion of the quality of local apples versus shipped-in fruit. Of the 61 dealers in the eight Virginia cities, 78 per cent voiced a preference for Virginia-grown fruit; 12 per cent preferred western fruit. Pennsylvania, West Virginia, and New York fruit was preferred by 6, 3, and 1 per cent, respectively. Although 49 per cent of these dealers say Virginia fruit is inferior in certain characteristics, 36 per cent say it is because of poor grading and packing, and only 13 per cent say it is because of poor quality. (Fig. 2.)

FIGURE 2.—Inferior specimens. Apples like these should go to the processing plants, not into barrel or basket. Finding too many of this kind in the packs has led many dealers to think that fruit from the Cumberland-Shenandoah region is inferior. Each of these apples exhibits a different type of injury

Forty-six per cent of the wholesalers consider Virginia fruit superior, showing that some Virginia growers are now putting up a satisfactory pack.

In 1926, recognizing the deficiencies of their grades and packs, the growers secured the passage of a State apple grading and marketing law, making compulsory the proper marking of grade, variety, and other characteristics on each closed package. This law had a beneficial influence on the grade and pack of commercial shipment of Virginia apples. (Fig. 3.) When questioned as to preference for containers, 39 per cent of the dealers preferred barrels, 32 per cent preferred boxes, and 29 per cent preferred baskets. When asked if a smaller package would be popular, 78 per cent said they thought it would.

Twenty-six dealers in eight Virginia cities distributed 50 per cent or more of the apples they bought to outside towns, reaching out more than 200 miles in a number of instances. Thus these cities are pri-

mary markets for a large consuming territory, and can dispose of more eastern fruit than the size of the city would suggest.

Retailers in Virginia cities rely on eastern apples to supply their trade. Only 3 per cent of their supply for 1926–27 was drawn from the West, and it was drawn largely during the last part of the season. West Virginia retailers drew one-sixth of their apples from the West.

The distribution of retailers' purchases during 1926–27 is shown in Table 11, by season of the year and by source of supply, for the retailers interviewed in Virginia and West Virginia. It is interesting that the Virginia retailers purchased 32 per cent of their supplies direct from growers, whereas the West Virginia retailers bought only 15 per cent from growers.

FIGURE 3.—Mechanical grader in a Virginia packing shed. A recent State law makes proper grading and marking of closed packages of apples compulsory. The grader makes it easy to pick out injured specimens, and mechanically sorts the fruit into lots of uniform size

TABLE 11.—*Apple purchases by retailers in Virginia and West Virginia cities from growers and wholesalers, by seasons, 1926–27*

State	Purchased from grower									
	Summer		Fall		Winter		Spring		Total	
	Bushels	*Per cent*	*Bushels*	*Per cent*	*Bushels*	*Per cent*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
Virginia	7,383	12.93	14,648	25.66	21,632	37.90	13,417	23.51	57,080	100.0
West Virginia	585	21.12	1,200	43.32	776	28.01	209	7.55	2,770	100.0

State	Purchased from wholesalers									
	Summer		Fall		Winter		Spring		Total	
	Bushels	*Per cent*	*Bushels*	*Per cent*	*Bushels*	*Per cent*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
Virginia	1,985	1.66	23,869	19.98	62,178	52.03	31,460	26.33	119,492	100.0
West Virginia	1,656	10.71	4,300	27.79	6,186	39.98	3,330	21.52	15,472	100.0

Retailers expect to break up the packages they buy to suit the convenience of customers. Small quantities are taken at a single-customer purchase, four-fifths of the volume reported having been doled out in lots of one-half peck or less. Seldom can a barrel be sold in the original package. Bushel baskets are sold more frequently than half bushels, but most city families have insufficient space to make purchase of more than enough for immediate use convenient. In Pennsylvania cities 10 per cent of the fruit sold at retail was sold by count. The practice of selling by weight is increasing, even when common measures are specified. (Table 12.) A 25-cent package is attractive to consumers in some cities.

TABLE 12.—*Size of retail sales as reported by retailers interviewed, 1926*

State	Percentage of apples sold in packages of size specified						
	Bushel	½ bushel	Peck	½ peck	¼ peck	By the pound	By count
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
West Virginia	7.8	2.1	11.4	3.9	6.6	67.9	0.3
Virginia [1]	6.05		17.90	27.96	19.85	17.32	3.27
Pennsylvania [2]	1.81	1.63	5.62	4.36	53.91	8.53	10.71

[1] In Virginia 7.65 per cent was sold under the quart size.
[2] The figures relate to the number of stores reporting the indicated size of retail sale as most frequent among their customers. In addition, 13.43 per cent of the stores specified the 25-cent package.

HEAVY SUPPLIES ADD TO MARKETING DIFFICULTIES

From 1910 to 1925 the number of apple trees in the United States decreased nearly 40 per cent. This was a decrease of 79,000,000 trees from a total of 217,000,000 trees reported in 1910. The main reason for this tremendous decrease was that apple supplies had become so heavy in the markets that the production could not be disposed of at prices remunerative to the growers. Even with this wholesale removal of apple trees, total production decreased only slightly, and commercial production increased steadily until within the last few years. In fact, supplies have been so large that a very high percentage of the crops of the last 15 years, 1914–1928, has sold below the general pre-war wholesale price level of all commodities.

Two striking illustrations of the effect of the apple supply on the grower's price have occurred during the last few years. Adverse weather conditions in 1921 resulted in one of the smallest crops on record, and favorable weather conditions in 1926 resulted in one of the largest crops ever produced. The small crop of 1921 was readily sold, and brought the growers of the United States an average of $1.95 per bushel; a part of the large crop of 1926 was left in the orchards, and the remainder was moved into consumption at considerable effort and at an average price to the growers of only 88 cents per bushel.

Annual variations in production and price must be expected, but the generally low purchasing power of apples during many of the last 15 years, 1914–1928, has been due to heavy supplies brought about by gross overplanting which took place during the period 1905–1912. The exploitation of the apple industry at that time overstimulated planting to such an extent that for years the apple industry underwent one of the most costly periods of readjustment. (Fig. 4.)

FIGURE 4.—In the process of readjustment, orchards like this must go. Unprofitable because of neglect, out of hand in growth, infested with insects and disease, this orchard probably can not now be rehabilitated. Fruit from orchards like this makes marketing difficult

Some idea of this adjustment and the possibilities of heavy future supplies may be had from the figures in Table 13.

TABLE 13.—*Apple trees of bearing age, 1925; average annual production 1922–1926; changes in number of trees 1910–1925; and number of trees and relative importance of young trees in commercial orchards in 1928, by groups of States*

Group of States	Trees of bearing age, 1925 [1]		Annual production,[2] 5-year average, 1922–1926		Percentage change in number, 1910–1925 [1]		Apple trees in commercial orchards, 1928 [3]		
					All trees	Trees not of bearing age	Total	Under 9 years old	Under 19 years old
	Millions	*Per cent*	*Million bushels*	*Per cent*	*Per cent*	*Per cent*	*Millions*	*Per cent*	*Per cent*
Western [4]	14.86	14.3	48.82	24.5	−5.7	−76.1	13.7	13.4	69.9
Central [5]	16.65	16.1	25.45	12.8	−55.1	−38.9	13.2	45.6	67.2
Cumberland-Shenandoah [6]	21.91	21.1	32.52	16.3	−7.0	−33.8	17.7	21.9	66.8
Michigan and New York	15.01	14.5	40.99	20.6	−19.1	−15.5	13.5	27.2	57.9
Delaware and New Jersey	2.25	2.2	4.43	2.2	+46.3	+36.6	2.7	34.8	82.5
New England	5.89	5.7	9.71	4.9	−23.9	−6.5	[7] 5.4	[7] 26.2	[7] 54.5
Other States	27.12	26.1	37.31	18.7	−51.3	−60.3	[8] 14.8	[8] 31.7	[8] 68.6

[1] Computed from reports of the Bureau of the Census.
[2] Estimates of Bureau of Agricultural Economics.
[3] Preliminary figures from a tree survey made by the Bureau of Agricultural Economics. Commercial orchards are defined roughly as orchards having 100 or more trees.
[4] Washington, Oregon, California, and Idaho.
[5] Missouri, Arkansas, Illinois, Tennessee, and Kentucky.
[6] Pennsylvania, Virginia, West Virginia, and Maryland.
[7] Five States—Maine, New Hampshire, Vermont, Massachusetts, and Connecticut.
[8] All other States except Rhode Island, Florida, Mississippi, Louisiana, Texas, North Dakota, South Dakota, and Nevada.

About 15 years ago (1909–1913 average) the Pacific Coast and Mountain States produced close to 19,000,000 bushels of apples per

year, but in recent years (1924–1928 average) they have produced more than 54,000,000 bushels annually. There is every indication that these Western States will continue to supply the markets with many apples, but the large yearly increases in production from the West are no longer in evidence. Western apple production was only slightly higher during the last five years than it was during the previous five years. The large decrease in the number of trees not of bearing age (76.1 per cent) from 1910 to 1925 in the four principal western apple States—Washington, Oregon, California, and Idaho—together with light plantings in late years, indicate that western production has been fairly well stabilized. These four States produce about one-fourth of the apple crop.

The large increase in production in the Western States had much to do with the removal of millions of apple trees in the Central States, and from 1910 to 1925 there was a net decrease of 31,000,000 trees in Arkansas, Missouri, Illinois, Kentucky, and Tennessee. During 1922–1926 these States produced about 13 per cent of the total apple crop. During late years plantings in these States have been rather heavy, and at the beginning of 1928 probably 46 per cent of the trees in the commercial orchards of the five States were under 9 years old. The heavy removal of trees and the following extensive new plantings in the region represent a shift in varieties and a shift to better locations, and probably indicate an increase in future market supplies from the region. (Table 13.)

Orchards of Michigan, New York, and New England contain a relatively large number of old trees, many of which are in good condition and producing good quantities of fruit. These States produce about 25 per cent of the total apple crop. During the eight years preceding 1928, commercial plantings per year amounted to an average of 3¼ to 3½ per cent of the number of trees in commercial orchards in 1928. There are tendencies toward improved production and marketing methods. The orchards in these States lie near many cities and undoubtedly will continue to maintain an important place in supplying consumers with eastern apples.

Delaware and New Jersey produce only about 2 per cent of the apples, but production in these two States is increasing and has practically doubled within the last 15 years. Unlike any of the other groups of States given in Table 13, both bearing and nonbearing trees have increased markedly, and recent plantings have been substantial; about 35 per cent of the trees in commercial orchards were under 9 years old in 1928. With reasonable care of the orchards, commercial production in these two States taken together will be maintained and may increase. A large part of any increase will be in the early varieties, and will not compete directly with production from the Cumberland-Shenandoah region.

The four States in which the Cumberland-Shenandoah region is located, producing about one-sixth of the apples grown in the United States, were extensively planted 15 to 20 years ago, and probably two-thirds of the commercial apple trees are under 20 years of age. Plantings during the eight years 1920–1927 have averaged annually about 2¾ per cent of the number of trees in commercial orchards in 1928, which means roughly that the rate of planting has been sufficient to maintain the number of trees, if the trees have an average life of 35 years. With improved methods of orchard management

now in evidence in the Cumberland-Shenandoah region an average life of orchards of 35 years or more appears to be at least a reasonable expectation, and it should be possible to maintain past production without difficulty. (Table 13.)

MARKET SUPPLIES OF SOME VARIETIES TO INCREASE

Although commercial apple production has increased during the last 15 years at a rate sufficiently high to keep prices to growers relatively low compared with prices of the things they buy, some varieties have sold relatively well. Consequently, some of the newer and more popular varieties have been extensively planted, whereas many trees of some of the older varieties have been removed or neglected.

In the United States there are over 800 standard varieties of apples in orchards. In the Cumberland-Shenandoah States there are 300 or more varieties. Only a few of these hundreds of varieties are or probably ever will be of real commercial importance, but in years of heavy apple production they add millions of bushels to already overloaded markets and add to the difficulties of moving the crop. In general, varieties not well known bring relatively low prices, especially when the production of such varieties is greater than what is needed to supply the few who are acquainted with them. Also, there are many varieties that are known locally but that are not wanted unless there is nothing better to be had.

Unless there is some way of popularizing the use of these less desirable varieties, there is little hope of profit from them in the future. In fact, the tendency for consumers to be more and more exacting in their demands for apples of better quality may be expected to increase rather than to diminish.

A large part of the apple production of the Cumberland-Shenandoah region is of varieties that are of generally recognized worth. Thus over 50 per cent of the trees in commercial orchards of the four Cumberland-Shenandoah States are of four varieties—York Imperial, Stayman Winesap, Winesap, and Delicious. Trees of these four varieties and of six others—Grimes Golden, Ben Davis, Rome Beauty, Jonathan, Arkansas (Mammoth Black Twig), and Yellow Newtown (Albemarle Pippin)—constitute 70 per cent of the trees in commercial orchards of these four States. It is generally considered, however, that the marketing situation in the region will be improved if the number of varieties is reduced to only a few of generally recognized merit. (Table 14.)

TABLE 14.—*Apple trees of specified varieties in commercial orchards in the Cumberland-Shenandoah States and in 40 States, 1928* [1]

Variety	Trees in commercial orchards		Percentage of designated variety			
			Under 9 years old		Under 19 years old	
	Cumberland-Shenandoah States [2]	40 States [3]	Cumberland-Shenandoah States [2]	40 States [3]	Cumberland-Shenandoah States [2]	40 States [3]
	Thousands	*Thousands*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
York Imperial	2,959	3,612	7.0	11.5	46.4	49.7
Stayman Winesap	2,382	5,073	28.1	38.5	88.2	89.1
Winesap	1,945	6,576	19.4	26.6	72.1	74.9
Delicious	1,291	6,991	49.8	56.5	97.2	96.0
Grimes Golden	783	2,418	28.2	36.6	82.6	78.1
Ben Davis	865	4,309	2.2	6.9	26.5	22.5
Rome Beauty	847	4,171	28.7	23.8	77.3	74.1
Jonathan	489	6,295	22.6	30.3	87.7	74.4
Arkansas (Mammoth Black Twig)	504	980	5.4	14.4	75.6	64.7
Yellow Newtown (Albemarle Pippin)	368	2,317	6.6	5.0	21.0	41.2
Other varieties	5,302	37,298	25.2	28.4	62.2	63.9
Total	17,735	80,040	21.9	28.7	66.8	67.4

[1] Preliminary figures from a tree survey made by the Bureau of Agricultural Economics.
[2] Virginia, West Virginia, Pennsylvania, and Maryland.
[3] All States except Rhode Island, Florida, Mississippi, Louisiana, Texas, North Dakota, South Dakota, Nevada, and a part of the following States: California, Oregon, Nebraska, and Ohio. Figures for California are for the 3 commercial apple districts of Watsonville, Sebastopol, and Yucaipa; for Oregon, figures are for all counties except Crook, Deschutes, Gilliam, Grant, Harney, Jefferson, Klamath, Lake, Morrow, Sherman, and Wheeler. Those for Nebraska are for the 7 counties of Richardson, Nemaha, Otoe, Cass, Sarpy, Douglas, and Washington. For Ohio, 48 counties in the southeastern, eastern, and northern part of State are included.

The York Imperial is the most extensively grown variety of the region. Probably not over 45 to 50 per cent of the trees of this variety are under 19 years old and only about 7 per cent are under 9 years old, so there is no present indication of any increase in the market supplies of this variety. (Table 14.) Other major varieties which have been only lightly planted here and in other States during the last several years are Ben Davis, Arkansas (Mammoth Black Twig), and Yellow Newtown (Albemarle Pippin). Along with these, some of the major varieties of other areas, such as Baldwin, Northern Spy, and Rhode Island Greening, have been planted only moderately during late years. Plantings of Grimes Golden and Rome Beauty, both popular varieties in parts of the region, have been heavy enough here and in other States to maintain production under favorable conditions.

If plantings of the last 8 to 10 years can be taken as a guide, there is every indication that market supplies of the Delicious will increase markedly as the trees of this variety, which are planted in the region and in nearly every other major apple State from coast to coast, come into bearing and approach full bearing capacity. In 1928 probably 96 per cent of the Delicious trees of the country were less than 19 years old, and more than 50 per cent were under 9 years old. (Table 14.) Principally in the New England States and in New York the McIntosh has been planted extensively during recent years. Probably few of the trees of this variety are over 20 years old and more than half of them have been planted during the last 8 to 10 years. This variety is almost certain to be found in increasing numbers on some of the

eastern markets where apples from the Cumberland-Shenandoah region are found. It is believed that plantings of the Jonathan, Stayman Winesap, and Winesap, both in the region and outside, have been ample to insure a continuation of the past volume of supplies of these varieties.

There are so many soil and climatic conditions in the Cumberland-Shenandoah territory that it is not always practicable for growers in the different sections to raise the same varieties to advantage. According to past plantings and production, the apple districts of Pennsylvania, West Virginia, and northern Virginia apparently are well adapted to the York Imperial, Ben Davis, Grimes Golden, Stayman Winesap, Jonathan, and Rome Beauty, whereas in the central and southern piedmont of Virginia the Winesap and the Yellow Newtown are outstanding varieties.

The effects of soil and climate on choice of variety is best observed in Virginia. In this State the apple belt extends for nearly 250 miles in a north-and-south direction. For purposes of comparison the apple belt of Virginia may be divided into five sections, three of which are in the piedmont region and two of which are in the valley region. Although the York Imperial is extensively planted in all sections, it is much more important throughout the valley and north piedmont than it is in the central and south piedmont sections, according to sales compiled for the 1926 crop. (Table 15.) The Yellow Newtown is likewise more important in the central piedmont section than in any of the others. The Stayman Winesap is important in the south piedmont and throughout the valley sections, and the Ben Davis is of greatest importance in the north valley section. The Delicious is of greatest importance in the south piedmont section. The Bonum is confined largely to the north piedmont section. Table 15 also indicates how unimportant many of the varieties are, but taken as a group they may add to the burden of moving heavy market supplies.

TABLE 15.—*Proportional distribution of sales by variety for different sections of Virginia, 1926 crop*

Variety	Central piedmont section	North piedmont section	South piedmont section	North valley section	South valley section
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
York Imperial	9.99	59.21	12.14	45.24	37.94
Winesap	59.27	8.25	5.49	1.80	9.47
Arkansas (Mammoth Black Twig)	1.79	2.15	1.69	9.08	2.92
Yellow Newtown (Albemarle Pippin)	18.07	4.92	9.09	2.55	4.29
Stayman Winesap	4.37	3.27	27.29	16.39	14.98
Grimes Golden	.96	1.55	2.99	4.26	1.29
Ben Davis	1.87	1.48	3.29	11.83	2.17
Delicious	.88	1.25	13.45	1.11	2.00
Jonathan	.39	.25	.49	1.38	.19
White Pearmain	.24	.04			
Yellow Bellflower	.04				
Arkansas Black	.07	.19	.08		
Bonum	.26	13.97	.49		.05
King David	.08	1.03	.17	1.20	.42
Rome Beauty	.39	.47	2.45	.85	.47
Kinnard	.48				
Gano		.03	.39	.75	.88
Black Ben		.59	12.67		1.01
Baldwin		.08	.05	.36	.02
Maiden Blush		.07		.14	
Winter Paradise		.08			.15
Oldenburg (Duchess)		.26		.62	
Virginia Red			1.01		.38
Fallawater			.05		

TABLE 15.—*Proportional distribution of sales by variety for different sections of Virginia, 1926 crop*—Continued

Variety	Central piedmont section	North piedmont section	South piedmont section	North valley section	South valley section
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Yellow Transparent				.07	.17
Buckingham			.44		
Limbertwig			2.46		
Northwestern Greening			.04	.46	
Lowry			.29		.08
Wealthy				.98	.05
Paragon		.05		.23	.01
Lawver (Delaware Red Winter)					.07
Mann					.23
Miscellaneous	.85	.81	3.49	.70	20.76

COLD STORAGE AN AID TO ORDERLY MARKETING

Apples must be stored every year to extend consumption over as long a period as conditions usually warrant. Whether dealer or grower stores is a matter of adjustment between individuals. In years of short or normal crops there is some expectation of enhancement of price through holding; in years of large crops there is hope of avoiding loss, as storing relieves the fall market of selling pressure. Available stocks in the spring supply active current demand. Growers in this region prefer to sell from the orchard, but most of them expect to store part of their crop or take a lower price.

Space for nearly 2,000,000 barrels of apples was available for the 1929 crop within the region (Table 16), and space for one-third as many more can be had at cities and towns in which apples may be marketed in the natural routine. (Fig. 5.) Storage warehouses in

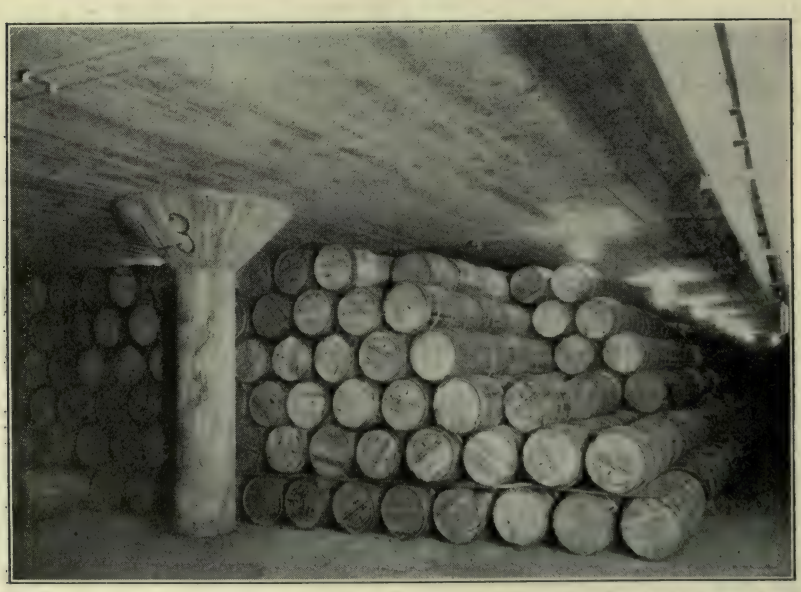

FIGURE 5.—Room in a cold-storage plant in Winchester, Va. Space for about 2,000,000 barrels of apples is available in the region

some local centers of production appear to be taxed to capacity each year. The larger warehouses are usually not filled to capacity, except in a year of record production, like 1926. Seasonal differences in practice respecting storage are indicated by the records of 13 cold-storage plants in Virginia, having a total rated capacity of 1,282,000 barrels of apples. In 1924 these plants were asked to handle apples to 53 per cent of capacity, and in 1925 to 46 per cent, as compared with 86 per cent in the heavy crop year 1926. (Table 17.)

TABLE 16.—*Cold-storage space available for apple storage by growers in the Cumberland-Shenandoah region, 1929*

Location	Rated capacity available within region	Available space sometimes used, accessible by truck or rail	Location	Rated capacity available within region	Available space sometimes used, accessible by truck or rail
Virginia:	*Barrels*	*Barrels*	West Virginia:	*Barrels*	*Barrels*
Winchester	730,000		Martinsburg	50,000	
Roanoke	185,000		Charles Town	50,000	
Richmond		178,000	Berkeley Springs	50,000	
Norfolk		125,000			
Charlottesville	114,000		Total	150,000	
Crozet	104,000				
Martinsville	60,000		Pennsylvania:		
Arrington	50,000		Biglerville	75,000	
Lynchburg	50,000		Waynesboro	72,000	
Shipman	45,000		Chambersburg	70,000	
Broadway	40,000		Gettysburg	50,000	
Staunton	40,000		York	22,300	
Berryville	35,000				
Harrisonburg	15,000		Total	289,300	484,400
Stuart	12,000				
Front Royal	5,000		Grand total	1,926,600	791,400
Danville		4,000			
East Radford	1,300				
Christiansburg	1,000				
Total	1,487,300	307,000			

TABLE 17.—*Capacity of 13 cold-storage warehouses in Virginia and quantity stored, 1924–1926* [1]

Plant No.	Capacity	Apples stored		
		1924	1925	1926
	Barrels	*Barrels*	*Barrels*	*Barrels*
1	325,000	161,460	200,266	346,582
2	140,000	79,667	75,822	147,333
3	40,000	29,272	22,963	5,164
4	40,000	30,500	11,637	27,133
5	75,000	41,667	27,733	64,416
6	110,000	18,000	65,000	93,471
7	44,000	40,847	28,710	41,946
8	104,000	114,000	25,000	113,000
9	50,000	23,018	20,955	46,654
10	60,000	10,166	14,300	57,433
11	78,000	67,763	54,954	70,675
12	100,000	40,214	23,406	58,238
13	116,000	23,008	22,405	24,578
Total	1,282,000	679,582	593,151	1,096,623
		Per cent	*Per cent*	*Per cent*
Percentage of capacity		53	46	86

[1] Boxes and baskets converted to barrels (3 bushels=1 barrel).

The seasonal nature of apple storage and the wide annual differences in volume of the business they are asked to perform makes it practically necessary for storage operators to handle other products than apples; moreover, almost all the plants sell ice and coal, and many of them sell cooperage as well. The plants begin to fill in October and reach a peak by December 1, when apples will have been moved from the orchard for sale or placed in cold storage for the winter. Few apples are held after April 1.

All of the apples worth moving out of the region are sold. The effort required is much greater in years of large crops than in years of small crops. In short-crop years dealers and buyers actively search for stock for their trade. In years of heavy crops sellers must search for markets and take lower prices or stand heavier selling expense. Difficulty in disposing of fruit is one of the main reasons for differences in prices paid to growers. This difficulty is not always the reason most apparent at the time of bargaining and is often obscured by the variable capacities of the individuals involved.

All through the marketing process the competition for the consumer's purchase is the basis of trading. Consumers pay the highest prices for apples of dessert quality. Exterior perfection of the fruit seems to have greater weight with city purchasers than quality of flesh or flavor. Few people will take blemished fruit of a good variety if perfect fruit of a less desirable variety is exhibited at the same time and place. Blemished fruit finds outlet at reduced price among the poorer classes as dessert fruit, or is used for cooking. Green-skin apples in general are not much wanted, except Greenings, which have long been prized for cooking. Yellow color has so long been associated with lack of color in red varieties that most yellow varieties find a market prejudiced against them, except well-known varieties. Few consumers now know or care about the variety offered them; the purchase is made on the basis of inspection and trial. As "the customer is right," retailers pay attention to variety only as a means of getting apples they can sell. This attitude of consumers is reflected back to producers through the retailers, wholesalers, and dealers.

Operators are about equally divided in opinion as to whether the growers have a regular policy with respect to storing certain varieties, and most of them say that price, current at harvest or prospective, governs the decision to store. Two-thirds of the operators interviewed reported that growers arranged for space in advance. Operators want apples brought in within 24 hours after picking, as delay in storing affects materially the conditions of successful storage. Ten days delay in putting the fruit in means that it must come out 30 days sooner than it would if stored promptly, according to one large operator.

In 1926 few apples below first-grade stock were put into storage; but when the crop is light, perhaps as many as a third of the quantity are below grade 1.

Operators of storage plants in Virginia were asked about the length of season for holding the several varieties. The end of the season for York Imperial was placed by some at January 1, and by others at each 15 days thereafter through April 1. Yellow Newtown could be held to the middle of July, according to one operator, but three thought April 1 the practical working limit. Similar differences were observed in the case of other varieties. These replies are interpreted as mean-

ing that apples of any variety, if treated properly with respect to picking, packing, placing in storage, and holding, can be held much longer than is ordinarily advisable for the general run of the variety. York Imperial was considered the variety most difficult to keep in cold storage. Winesaps were called the best keepers, varietal season considered, followed closely by Yellow Newtown.

SOME VARIETIES SELL BETTER THAN OTHERS

Prices for the different varieties vary so much from year to year and the causes are so many that the grower finds it difficult to decide just which varieties to grow. He may have reached the conclusion that a certain variety is unprofitable, only to have his calculations upset by some unusual condition. The circumstances that caused a very profitable price situation for Ben Davis just after the first of the year in 1929 is an example of the sort of thing that may happen. The 1928 crop of the Baldwin in New York was short, which would normally indicate a favorable situation for the York Imperial, its chief competitor. However, the York Imperial scalded badly during the later months of the 1928–29 season, resulting in a shortage of good barreled stock. The Ben Davis, which was of unusually good appearance in 1928, then found a ready demand at very satisfactory prices.

Although there are such instances, it is true that over a period of years there are marked price advantages in growing certain varieties. The average prices received by growers for the 10 outstanding varieties for the three crops, 1924–1926, are given in Table 18. Classified according to average price, ranked from highest to lowest, these varieties came in the following order: Yellow Newtown (Albemarle Pippin), Rome Beauty, Winesap, Delicious, Jonathan, York Imperial, Stayman Winesap, Grimes Golden, Arkansas (Mammoth Black Twig), and Ben Davis.

TABLE 18.—*Price per barrel received by growers for designated varieties, 1924–1926 crops*

Variety	Average price	Barrels sold	Trees of designated variety in 1928 [1]
	Dollars	*Number*	*Per cent*
Yellow Newtown (Albemarle Pippin)	4.75	43,885	2.1
Rome Beauty	3.42	8,244	4.8
Winesap	3.29	89,020	11.0
Delicious	3.27	10,446	7.3
Jonathan	2.81	22,958	2.7
York Imperial	2.80	498,938	16.7
Stayman Winesap	2.74	118,989	13.4
Grimes Golden	2.67	78,311	4.4
Arkansas (Mammoth Black Twig)	2.64	48,455	2.8
Ben Davis	2.60	95,753	4.9
Other varieties			29.9

[1] Estimated trees in commercial orchards of Pennsylvania, Virginia, West Virginia, and Maryland, Jan. 1, 1928. For number of trees see Table 13.

A lack of color in the Stayman Winesap and its susceptibility to scald are no doubt important causes why this variety sells as low as it does on the market. The Grimes Golden, an excellent apple, is frequently picked too green, and therefore does not have the appearance, nor does it develop the flavor, desired by the consumer. As this

variety is light in color, it presents a poor appearance if there are blemishes of any sort on the skin. Poor appearance, due to discolorations or blemishes caused by disease and insects, may be largely prevented through adequate spraying. And so it is with every variety; something omitted or not done well or not done at the right time may affect the fruit so that the price is lowered. Generally, factors such as grade, size, color, pack, and quality are some of the main price determinants of any and all varieties, and are discussed elsewhere in this bulletin.

The prices given in Table 18 are averages for the sales compiled for three crops, 1924–1926. They represent what the growers received for the quantities sold. These quantities varied tremendously, but the prices of the different varieties did not vary with the relative supply of the varieties. Thus Ben Davis, Arkansas, and Grimes Golden apples brought the lowest average prices, even though the combined production of these three varieties in the region is much less than that of York Imperial, Winesap, or Stayman Winesap. Neither are supplies of Yellow Newtown, Rome Beauty, Delicious, and Jonathan from the region heavy when compared with supplies of the York Imperial, Stayman Winesap, and Winesap, and under present conditions prices of these varieties are all relatively good.

Thus the data indicate that many more apples of some of the varieties grown in the region are taken by consumers and at a higher price than is paid for smaller quantities of some of the other varieties. These price differences probably indicate in a rough way consumers' preference, but do not by any means indicate how far production of these varieties can be expanded before the price declines materially. Future increases in production of some of the more desired varieties, as indicated in Table 14, may lower the price level for these varieties, but probably will have a greater effect on apples of obsolete varieties, making it even more difficult than it is at present to dispose of any quantity of them.

Of course, the individual grower must make the most of the orchard he has. By using the best methods of orchard management and the best marketing practices he will probably do the best that can be done under his particular set of conditions. Under most conditions in the region, the best is good enough to make orcharding fascinating and profitable. Where the burden is too heavy, because of too large a proportion of poor and obsolete varieties, because of poor soil, poor location, or other basic defects of the orchard, there is little hope for profits until a plan is worked out and put into operation that will remedy such defects. Such a plan of reorganization might well enough extend over several years.

PRICES DIFFER IN VARIOUS PARTS OF REGION

Even as prices differ for the same variety grown in different orchards, so do they differ for fruit of the same variety from different parts of the region. These differences are illustrated by price data for 11 varieties grown in five sections of Virginia in 1926. (Table 19.)

TABLE 19.—*Average price per barrel received by growers in different sections of Virginia for 1926 crop* [1]

Variety	Central piedmont section	North piedmont section	South piedmont section	North valley section	South valley section
York Imperial	$2.34	$1.97	$2.78	$2.15	$1.56
Winesap	3.09	2.03	2.72	2.47	4.29
Arkansas (Mammoth Black Twig)	2.01	1.94	2.83		2.31
Yellow Newtown (Albemarle Pippin)	2.46	3.64	4.01	4.26	4.35
Stayman Winesap	2.27	1.69	1.95	2.13	1.33
Grimes Golden	1.69	3.36	1.72	2.29	1.37
Ben Davis	2.20	2.70	1.84	1.67	1.46
Delicious	2.25	3.33	2.03	2.19	3.47
Jonathan	1.24	5.10	3.82	3.43	6.36
King David	3.06	3.41	2.86	3.90	3.68
Rome Beauty	2.94	2.73	1.42	3.75	2.06

[1] Central piedmont includes counties of Albemarle, Amherst, and Nelson; north piedmont includes counties of Madison and Rappahannock; south piedmont includes counties of Franklin, Patrick, Pulaski, Smythe, and Wythe; north valley includes Frederick County; and south valley includes counties of Augusta, Rockingham, Botetourt, and Roanoke.

The average prices received by growers for all varieties in different sections of the State for barreled stock of the 1926 crop were as follows: Central piedmont, $2.80; north piedmont, $2.41; south piedmont, $2.31; north valley, $2.10; and south valley, $1.83. The causes of variations in prices of apples from the different sections are not measurable with the data at hand. The figures in Table 19 are presented here as a source of information, with the suggestion that individual growers may profit by closely observing their own problems and by applying practical remedies thereto.

Conditions surrounding the unusually large crop of 1926, when, at the discretion of individuals, apples of various varieties, grades, sizes, and condition were not gathered, may be responsible for at least part of the differences in prices received by growers in different sections. However, it is interesting that within a given section of the State some varieties brought the growers two or three times as much per barrel as did other varieties. Then, again, the figures in Table 19 indicate that some particular variety may have brought the growers of one section two or three times as much as did the same variety in some other section. It is probably within the power of the growers to get better prices for some of the varieties in sections where the average is low, through better cultural and marketing practices. If such improvement is not feasible, there is a serious question of the wisdom attached to the original planting of such varieties in such locations.

When the price figures are averaged for each State by years, variations in prices similar to those indicated for various sections of Virginia were found. One fairly definite indication from these figures is that the prices received for apples from Pennsylvania, in the case of those varieties common to all three States, were frequently somewhat above average prices shown for the sales from the other States. (Table 20.) This indication bears out other general conclusions arrived at during the study, to the effect that the Pennsylvania orchardists as a class are making the apples of their section conspicuous in local markets as an article of commerce really wanted by consumers. One of the needs of the region as a whole is a concerted effort on the part of all growers to produce and pack apples that will

command respect whenever and wherever offered for sale. Especially is this essential for those varieties that have strong competition from other areas.

TABLE 20.—*Average price per barrel received by growers for designated varieties, all grades and sizes, by State of origin,*[1] *crops of 1924–1926*

Variety	Crop of 1924			Crop of 1925			Crop of 1926		
	Virginia	West Virginia	Pennsylvania	Virginia	West Virginia	Pennsylvania	Virginia	West Virginia	Pennsylvania
Arkansas (Mammoth Black Twig)	$3.31	$4.21	------	$3.70	$4.08	$5.22	$2.08	$2.34	$2.24
Ben Davis	3.21	3.57	$3.67	2.63	3.03	3.39	2.30	3.14	2.30
Bonum	------	------	------	2.59	------	------	3.35	------	------
Delicious	4.03	------	------	3.89	3.72	3.97	3.13	2.74	2.59
Gano	3.81	------	5.70	2.87	------	------	2.79	2.45	2.45
Grimes Golden	3.43	3.76	3.70	3.52	3.51	3.76	2.20	1.78	1.85
Jonathan	4.74	4.18	------	3.53	2.79	3.98	2.71	1.75	2.00
King David	3.70	------	------	3.19	------	------	3.65	------	2.22
Northwestern Greening	2.41	3.57	------	2.76	4.13	------	4.01	1.84	------
Rome Beauty	3.45	------	3.38	4.42	1.68	4.83	2.27	2.98	3.67
Stayman Winesap	3.84	4.42	3.73	3.86	1.92	4.37	2.90	2.22	2.29
Winesap	4.35	4.61	------	4.40	4.18	------	2.61	2.80	1.15
York Imperial	3.26	3.08	4.08	3.30	3.36	3.75	2.50	2.45	2.34
Yellow Newtown (Albemarle Pippin)	6.00	------	------	4.45	------	------	3.95	------	------

[1] Prices paid to grower for apples packed in barrels and delivered at shipping point.

PRICES OF VARIETIES INFLUENCED BY TIME OF SALE

In the region as a whole, probably 70 per cent of the apples have left the farmers' control by December 1. As the season progresses prices of the late varieties usually increase. Exceptions to this general rule are found for some varieties in some seasons, and occasionally a variety "sells off" during the latter part of the season because of a decline in quality.

The movement of the Virginia crops of 1924, 1925, and 1926, as represented by the compiled sales data for the leading varieties, is probably typical of conditions in the region. (Table 21.) The extreme fluctuations for the minor varieties may be due to the small number of observations. The figures are averages for the three seasons. Only slight variations from these averages occurred during any of these three seasons. The early varieties, such as Oldenburg (Duchess), Yellow Transparent, and Williams, are disposed of by September 1. Such varieties necessarily must be sold in season.

The King David and the Northwestern Greening are practically all sold by October. The King David, a fall apple, is harvested early for the English market. Growers have a tendency to dispose of each of the varieties at the season when it is most suitable for consumption, but a large percentage are sold to dealers who put them on the market at once or place them in cold storage. For example, the Winesap, which keeps well until late winter and spring, is placed on the market in large quantities before January 1. About 59 per cent of the Winesaps included in the Virginia sales records left the farmers' control before January 1, and approximately 35 per cent of this variety was marketed by the growers before November 1. There is a more pronounced tendency for the grower to hold the Yellow Newtown for spring markets, but 20 per cent of the Yellow Newtowns included

in the Virginia sales records were marketed before January 1. No doubt the avoidance of cold-storage charges has much to do with the general tendency to market apples early.

TABLE 21.—*Proportionate average sales during the marketing season*[1] *of specified varieties of Virginia apples, by dealers reporting sales crops of 1924–1926*

Variety	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Arkansas (Mammoth Black Twig)				24.3	28.3	25.8	8.9	8.1	1.9	0.5	2.2	
Baldwin			35.2	53.4	1.0	.5	9.9					
Ben Davis			29.7	33.7	14.1	5.5	3.6	9.2	3.0	1.2		
Ben Hur				65.1		28.3			6.6			
Black Ben			1.0	18.5	33.8	17.5		10.4	4.0		14.8	
Bonum		8.7	79.6	11.4	.3							
Collins				52.8	.6	43.6	.6					2.4
Delicious			36.3	29.8	5.0	3.8	5.7	5.8	5.8	6.3	.1	1.4
Early Harvest	100.0											
Fallawater			25.7	74.3								
Gano			45.6	23.4	8.0	3.8	1.4	4.4	10.3		3.1	
Grimes Golden		.7	63.4	28.3	.8		3.6	1.2	1.9		.1	
Jonathan		.1	49.6	48.4		.1	.4	1.4				
King David	15.5	32.7	44.9	6.3	.5			.1				
Lowry			39.5	30.2	6.7	.2	2.2	6.5	7.9	3.5	3.3	
McIntosh			100.0									
Maiden Blush		15.2	84.8									
Nansemond				100.0								
Northern Spy			17.4	34.8				47.8				
Northwestern Greening		15.2	81.4	2.1	1.3							
Oldenburg (Duchess)	60.0	40.0										
Rambo			8.7	91.3								
Rome Beauty			9.3	56.1	18.5	1.7		8.7	5.7			
Smokehouse			92.9	7.1								
Springdale					29.8	70.2						
Stayman Winesap			3.2	42.9	16.7	10.4	10.7	8.1	5.3	.3	2.4	
Virginia Beauty			72.0	12.6	15.4							
Williams	75.0	25.0										
Winesap		.1	.5	35.0	18.4	5.3	3.1	9.2	13.9	9.0	5.0	.5
Winter Paradise		7.7	3.5	37.1	18.4	16.1	11.6	2.8	1.7		1.1	
Wolf River		17.6	82.4									
Yellow Newtown (Albemarle Pippin)			7.2	1.8	7.9	3.1	1.1	14.1	17.4	17.8	24.0	5.6
Yellow Transparent	66.4	29.8										3.8
York Imperial	4.1	2.8	17.4	38.9	21.6	7.8	3.8	2.8	.6	.1	.1	

[1] Each variety taken as a unit. Total sales reported for the variety equals 100 per cent.

It has been the practice of many growers to market at least a part of their apples as early as possible because of the favorable prices for the first fall and winter fruit to reach the markets. Sometimes there is a tendency to market the fruit when it is rather immature; this practice is believed to leave a bad impression on the market and results in a slacking in prices if carried to excess. A more important influence on the prices received in October and November is the tremendous quantities of fruit put on the markets during these months.

Nearly 25 per cent of the York Imperial included in the Virginia sales records went to market before October 1, and 4 per cent were sold as early as July. In 1926, owing to the prospects for an unusually large crop, the growers placed large quantities of this variety on the market before October 1. Of the York Imperial shipped to market during the month of August, 84 per cent went to foreign markets in 1924, and 100 per cent went to foreign markets in 1926 because the English apples are not mature at that time. (Table 22.) The flow to market is controlled by the proportion of apples put in storage and marketed at different times during the winter months. When there is an average crop or a small one, prices are likely to advance as the season progresses. However, the condition of the apples,

possible future prices, and cost of storage must be considered in deciding whether to store. When there is an excessive crop, as in 1926, the problem of whether to store becomes most difficult. In that year prices were highest up to November, when there was a considerable drop, and a low price prevailed for the remainder of the marketing season. About the best the individual grower can hope to do is to study the situation each year, and each year decide what is best under his conditions.

TABLE 22.—*Proportionate monthly sales reported of Virginia York Imperial to domestic and foreign markets and average prices to growers, crops of 1924–1926*

Month	Sold in domestic markets			Sold in foreign markets			Price per barrel received by growers					
							Domestic sales			Foreign sales		
	Crop of 1924	Crop of 1925	Crop of 1926	Crop of 1924	Crop of 1925	Crop of 1926	Crop of 1924	Crop of 1925	Crop of 1926	Crop of 1924	Crop of 1925	Crop of 1926
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
July						100.00						2.64
August	15.52			84.48	100.00	100.00	3.35			2.83	3.75	2.88
September	47.37	46.35	17.71	52.63	53.65	82.29	3.44	3.19	2.34	3.37	2.88	2.65
October	47.84	39.90	23.65	52.16	60.10	76.35	3.36	3.19	2.30	3.13	3.08	2.31
November	41.56	24.28	20.46	58.44	75.72	79.54	3.30	3.42	1.87	2.61	3.34	1.79
December	47.74	52.91	2.63	52.26	47.09	97.37	4.63	3.65	2.52	2.73	3.95	1.83
January	36.85	1.79	6.37	63.15	98.21	93.63	4.58	4.25	1.00	3.52	4.34	2.35
February	88.79		12.25	11.21	100.00	87.75	2.51		.77	4.09	3.37	1.80
March				100.00	100.00	100.00				3.18	2.26	1.25
April	100.00					100.00	4.75					2.03
May	100.00		100.00				2.51		2.24			

VARIETIES HANDLED IN LOCAL MARKETS

Surprise is frequently expressed at the large quantities of apples brought from outside sources into the cities of the States in which the Cumberland-Shenandoah region is located when growers of the region are shipping to outside cities, some of which are many hundreds of miles away. No doubt consumers in the States in which the Cumberland-Shenandoah region lies have as much city and State pride as consumers elsewhere, but they buy their apples from the local retail store; so far as possible they get what they want or what they can afford, and they are not much interested in who grew the apples. The retailer makes a practice of handling certain varieties which experience has shown to be acceptable to his trade. He buys these varieties wherever and whenever he can direct from the growers or from wholesalers. Whether it be the wholesaler or retailer who makes the original purchase, he is willing to "shop around" just as other folks do until he gets what he wants. Some of the things that determine where he buys a particular variety are size, color, grade, quality, price, and quantity of supply. Any section that grows a desired variety that meets the wants of a buyer has a good chance of selling apples to him, whether he be located near by or a thousand miles away.

Of the 1926 apple crop, the city of Philadelphia took more than 390,000 bushels (delivered by motor truck, wagon, and in small lots by other means), and 2,251 carloads (delivered by rail in car lots). This supply was composed largely of favorite early varieties and of later varieties generally grown in the Cumberland-Shenandoah region. Such varieties as Stayman Winesap, Winesap, Baldwin,

Rome Beauty, Delicious, York Imperial, and Grimes Golden were leaders in that market. (Tables 23 and 24.)

TABLE 23.—*Supply of designated varieties of apples received in carloads in Pennsylvania and Virginia cities, crop of 1926*

Variety	Philadelphia, Pa.	Pittsburgh, Pa.	15 other Pennsylvania cities [1]	7 Virginia cities [2]	24 Pennsylvania and Virginia cities
	Number	*Number*	*Number*	*Number*	*Number*
Stayman Winesap	682	212	100	34	1,028
Winesap	314	321	64	52	751
Baldwin	132	417	106	6	661
Rome Beauty	126	210	66	6	408
Yellow Transparent	5	260	13	[3]	[4] 278
Delicious	106	116	18	7	247
York Imperial	101	23	20	17	161
Grimes Golden	43	51	13	8	115
Arkansas (Mammoth Black Twig)	27	35	36	2	100
Yellow Newtown (Albemarle Pippin)	[3]	[3]	[3]	6	[4] 6
Jonathan	[3]	[3]	[3]	4	[4] 4
Other	715	883	25	31	1,654
Total	2,251	2,528	461	173	[4] 5,413

[1] Cities of Chambersburg, Connellsville, Coatesville, Dubois, Erie, Harrisburg, Huntingdon, Johnstown, New Castle, Reading, Scranton, Shamokin, Washington, Williamsport, and York.
[2] Cities of Bristol, Danville, Lynchburg, Norfolk, Richmond, Roanoke, and Staunton.
[3] This variety when and if unloaded in the indicated cities was included in "other" varieties.
[4] These totals do not include possible unloads of the indicated varieties in the Virginia and Pennsylvania towns marked by ([3]).

TABLE 24.—*Supply of designated varieties of apples received by wholesalers in Pennsylvania and Virginia cities by motor truck, wagon, and in less than carload shipments, crop of 1926*

Variety	Philadelphia, Pa.	16 other Pennsylvania cities [1]	7 Virginia cities [2]
	Bushels	*Bushels*	*Bushels*
Stayman Winesap	131,250	17,450	4,374
Winesap	78,750	8,700	34,951
Rome Beauty	59,060	8,625	600
Baldwin	----------	12,350	----------
Jonathan	----------	7,250	----------
Yellow Transparent	----------	4,123	1,050
Delicious	----------	2,762	3,409
Greening [3]	----------	2,150	----------
Northern Spy	----------	2,000	----------
York Imperial	----------	----------	7,734
Yellow Newtown (Albemarle Pippin)	----------	----------	5,482
Grimes Golden	----------	763	2,211
Ben Davis	----------	----------	1,140
Other	124,690	60,832	17,916
Total	393,750	127,005	78,867

[1] Includes cities indicated in footnote 1, Table 23, and Pittsburgh.
[2] Includes cities indicated in footnote 2, Table 23.
[3] Probably includes both Northwestern Greening and Rhode Island Greening.

Pittsburgh received nearly all of its supply in car lots and took heavily of the same varieties. Fifteen other smaller cities of Pennsylvania and seven cities of Virginia were heavy takers of these varieties, both in car lots and in smaller lots, delivered by motor truck, wagon, and rail. True, some of these 24 cities used fair to relatively small quantities of such varieties as Baldwin, Northern Spy, and others not generally grown in the region, but on the whole a very high

percentage of the apples consumed in these 24 cities were of the varieties grown in the region.

It can not be said that these Pennsylvania and Virginia cities used these varieties merely because they were grown in the States of which these cities are a part; rather it must be concluded that consumers in these cities used apples of the varieties grown in the region, because the region grows, in a commercial way, a large number of the most popular varieties grown anywhere in the United States. Consequently, these growers have a number of varieties that can be sent into any part of the country (some of them can also be sent abroad), and find dealers who know the varieties and who welcome an opportunity to handle them, if they are of the grade and quality desired. This statement holds just as true for growers in other parts of the country, for many of these varieties are grown extensively elsewhere.

Of the 2,251 carloads of apples of the 1926 crop that were unloaded in Philadelphia, less than one-third were from four States—Pennsylvania, Virginia, West Virginia, and Maryland. A few Baldwin and Rhode Island Greening were brought in from New York. Delaware furnished a part of the supply, but the Pacific Coast States of Oregon, Washington, and California shipped in more than 52 per cent of the total car-lot supply. Stayman Winesap, Winesap, Jonathan, Yellow Newtown, Rome Beauty, and Delicious made up practically all of the western supply.

Of the 2,528 cars of the 1926 crop unloaded in Pittsburgh, less than 30 per cent were from the four States in which the Cumberland-Shenandoah region is located. New York State supplied 33 per cent of the apples unloaded in Pittsburgh, and Delaware, New Jersey, Ohio, Indiana, and Illinois combined supplied 8.4 per cent. Washington, Oregon, Idaho, and California together supplied 28 per cent of the apples unloaded. Pittsburgh unloaded apples of more than 28 varieties, but over half of the supply was made up of varieties grown commercially in the Cumberland-Shenandoah region. Baldwin supplied very largely by New York State, was the leading variety in the Pittsburgh market. Of the apples supplied from the Western States, 92 per cent were of the Winesap, Stayman Winesap, Rome Beauty, Delicious, Jonathan, and Esopus Spitzenburg varieties.

Similar details are not available for all of the other 22 cities of Pennsylvania and Virginia. Figures for the seven Virginia cities indicate that about 87 per cent of the apples of the 1926 crop unloaded were from Virginia, 6 per cent were from other Eastern States, and only 7 per cent were from Western States. Richmond, the largest car-lot receiver of the seven Virginia cities studied, was a heavy user of Winesap, Stayman Winesap, and York Imperial.

Apparently these Virginia dealers handle Virginia-grown apples because they prefer them to apples brought in from outside. This is probably reflected in the consumers' willingness to buy locally grown apples at prices at which they are offered. Thus these Virginia city wholesalers stated that they preferred to handle such varieties as Winesap, Stayman Winesap, York Imperial, Yellow Newtown, Grimes Golden, and Rome Beauty. They generally preferred to handle apples grown in their own State, although a few expressed preference for apples from other parts of the Cumberland-Shenandoah region and others preferred to handle western-grown apples. These expressions of preferences reflect what the wholesalers are actually doing; they

can not be expected to reflect opinions that would develop if each dealer were to handle apples of various varieties from the different apple regions. Even then conclusions as to consumers' wants for various varieties of apples and for apples from different sections might be misleading unless due allowance were made for differences in prices. That is, there are two classes of buyers—the one buys what he prefers, so far as it can be obtained, and the other buys what he can afford.

At any rate, these Virginia wholesalers generally felt that when everything was considered, such as quality, appearance, and price, the local apples were better for their trade than most apples brought in. However, a large percentage of the wholesalers felt that the pack was inferior to packs from many other sources and that it could be improved and standardized to advantage.

A majority of wholesalers in the Pennsylvania cities (not including Chambersburg, Huntingdon, Pittsburgh, and Philadelphia), expressed preferences for Pennsylvania apples. Just as many were enthusiastic about handling western apples, and a goodly portion thought well of the apples shipped in from New York State. These expressions naturally were in line with what they were actually handling. For example, the Baldwin sold well in some of these Pennsylvania cities, and, since it came from New York, the wholesalers who handled it preferred to handle apples from that State. Again, wholesalers in some of the Pennsylvania cities have built up a good business for boxed apples from the West, and naturally prefer to handle apples from that region.

The majority of these Pennsylvania city wholesalers preferred to handle apples packed in baskets or boxes, and this may have had something to do with the sources of supply. Although a few of these wholesalers stated that the quality of the local apples was superior to that of apples from other sources, the great majority felt that locally grown apples were of inferior quality. This was interpreted as meaning that grade, appearance, condition, and pack leave much to be desired from the consumers' point of view.

This study did not inquire into the reception generally accorded Cumberland-Shenandoah apples in cities outside of the four States of which the region is a part. It might be logically inferred, however, that the reception in distant cities is at best generally no better than it is at home. The region grows many varieties that are not well known or that are not generally wanted at relatively good prices. This situation should be improved as time passes. On the other hand, the region has a number of varieties that are generally well known and that have received the stamp of approval of large numbers of consumers. For these varieties to hold their place with the same varieties from other regions, a concerted effort is needed which works toward a good product—a product that has quality. uniformity, and dependability.

GRADE AN IMPORTANT PRICE FACTOR

Uniform grading according to adopted standards and accurate marking of sizes assist greatly in obtaining top market prices. According to the sales records, apples grown in the Cumberland-Shenandoah region were marketed by dealers in 10 different sizes and under a number of different grade descriptions. The grades generally

recorded were United States Fancy, United States No. 1, United States Commercial, United States No. 2, Unclassified, and Bulk.[2] Dealers sell a comparatively small quantity of the bulk apples sold in the region, most of them being sold direct by growers. Many apples are sold "tree run" by growers to buyers who pack and sell them. The proportion of apples packed as No. 1 varies considerably from year to year, as illustrated for 10 varieties in Table 25. For the region as a whole these fluctuations depend largely upon climatic effects during the growing season, on the finish of the fruit, and to some extent on tree management and market conditions.

TABLE 25.—*Grade composition of reported sales of 10 varieties of Virginia apples, 1924–25, 1925–26, and 1926–27*

Season	Grade	Arkansas (Mammoth Black Twig)	Ben Davis	Delicious	Gano	Grimes Golden	Jonathan	Stayman Winesap	Winesap	Yellow Newtown (Albemarle Pippin)	York Imperial	Total
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1924–25	No. 1	45.9	24.0	65.1	------	76.3	68.1	50.9	48.5	15.4	52.0	45.7
	No. 2	23.4	10.1	16.8	56.7	3.7	31.9	14.3	19.4	61.1	4.0	18.3
	Unclassified	14.0	44.6	18.1	43.3	10.0	------	27.6	16.0	21.5	25.0	21.8
	Bulk [1]	16.7	21.3	------	------	10.0	------	7.2	16.1	2.0	19.0	14.2
1925–26	No. 1	56.1	------	78.0	14.4	44.2	------	49.0	62.6	51.1	35.9	39.9
	No. 2	12.1	------	14.7	85.6	16.3	12.0	28.3	8.4	16.8	6.2	10.2
	Unclassified	31.8	100.0	6.7	------	39.5	88.0	19.4	28.1	32.1	54.1	47.2
	Bulk [1]	------	------	.6	------	------	------	3.3	.9	------	3.8	2.7
1926–27	No. 1	61.6	62.4	73.5	63.6	47.2	42.8	67.0	70.2	48.6	51.2	57.6
	No. 2	5.4	6.1	6.1	9.3	4.7	.9	3.6	12.8	24.0	1.4	5.6
	Unclassified	18.0	31.5	20.4	23.7	45.8	56.3	17.5	16.5	27.4	45.8	33.6
	Bulk [1]	15.0	------	------	3.4	2.3	------	11.9	.5	------	1.6	3.2

[1] Bulk apples are of various grades; all grades included as reported.

The unclassified Virginia pack varied during the three seasons from 21.8 per cent of the total in 1924–25 to 47.2 per cent in 1925–26 for the 10 varieties shown in Table 25. The quantity packed in the unclassified grade exceeded the quantity packed in grade No. 1 in the 1925–26 season. The No. 2 grade constituted a larger proportion of the apples sold in 1924–25 than it did in either of the other two seasons. In this table the four grades (No. 1, No. 2, Unclassified, and Bulk) represent 100 per cent; apples of other grades were not included because of the relatively small quantities reported in each grade. Since these data were collected the United States Commercial grade has come into importance, and recently considerable quantities of this grade have been packed.

Not only is there a variation in the total quantities packed under different grades from year to year, but within any year there is considerable variation in quantities packed under the different grade classifications for the various varieties. The factors causing rejec-

[2] For the crop years covered by the survey, 1924–1926, many apples from the region were sold under various unstandard descriptions. It is likely that some of the apples designated as No. 1 and No. 2 are inferior to U. S. No. 1 and U. S. No. 2. U. S. Commercial and U. S. Unclassified were not promulgated until 1926, previous to 1926 Unclassified was known as U. S. No. 3. Effective July 1, 1928, rules and regulations for grading, packing, and inspection of Virginia apples were established. Grades at that time for apples packed in containers other than boxes were the same as the United States official standard for the inspection of apples, except the grade "Virginia Early Export." Recently "U. S. Utility" has replaced U. S. No. 2 in the United States official standard for the inspection of apples.

tion from No. 1 grade are numerous and vary to some extent with the different varieties. The outstanding cause among red varieties for failure to make No. 1 grade is lack of color.

Although unfavorable climatic conditions, insects, and diseases have great influence on the grade of an apple, it was found that much of the responsibility for the grades produced rests with the grower. Figures for 13 West Virginia growers, who represent a typical regional group of producers, show varying abilities in producing apples of United States No. 1 grade. (Table 26.) The percentage of No. 1 apples produced by the different men in 1926 varied from 40.88 to 88.58 per cent of their total production.

TABLE 26.—*Percentage distribution of grades of apples packed by 13 growers in West Virginia in 1926*

Grower No.	United States No. 1	United States No. 2	United States Commercial	Canner	Cider apples	Grower No.	United States No. 1	United States No. 2	United States Commercial	Canner	Cider apples
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	88.53			7.62	3.80	8	55.04		5.80	30.23	8.93
2	84.73			10.96	4.31	9	54.69	.11		28.73	16.47
3	72.98	0.06		19.28	7.68	10	54.20	19.00	1.95	18.87	5.98
4	69.38	.15	0.01	20.77	9.69	11	49.87	.60	1.09	40.18	8.26
5	67.29			26.40	6.31	12	45.08	8.52		37.82	8.58
6	56.08	.20	9.64	27.84	6.24	13	40.88		1.98	51.22	5.92
7	55.91			36.23	7.86						

During the three crop seasons 1924–1926, 46 to 87 per cent of the annual sales studied of Virginia York Imperial apples in domestic markets were of grade No. 1, whereas only 29 to 49 per cent of those sold in foreign markets were of grade No. 1 apples. (Table 27.)

When fruit finishes poorly or when there is a large crop, the tendency has been to ship relatively larger quantities of the apples that grade below No. 1 to foreign countries.

TABLE 27.—*Percentage that No. 1 grade apples are of total domestic and foreign sales studied of Virginia York Imperial, by seasons*

Year	Domestic		Foreign	
	No. 1 grade	Unclassified and other	No. 1 grade	Unclassified and other
	Per cent	*Per cent*	*Per cent*	*Per cent*
1924–25	87	13	49	51
1925–26	46	54	29	71
1926–27	86	14	39	61

In general, apples packed in this region are not carefully sorted according to grades. For example, when packing for the United States No. 1 grade some growers will barely meet the tolerance limit for color, whereas other growers will pack under a United States No. 1 grade many apples with sufficient color to meet United States Fancy grade requirements. There is enough difference, therefore, in the character of United States No. 1 packs to cause a variation of

as much as $1 per barrel, and frequently more, in the prices that will be paid for different United States No. 1 packs.

Since there are no color limits or other requirements for apples packed under the Unclassified grade, there is a much greater variation in the character of apples packed in this grade than of those packed under standard grades. Likewise there is a much greater variation in the prices received for different Unclassified packs. Many growers pack Unclassified grade because of unfamiliarity with the requirements of the various standard grades. Growers in some States are forbidden by law to misbrand packed apples, and fear of conflict with the law causes some growers to pack apples under the label "Unclassified." Other growers pack apples under the Unclassified grade because such packing requires a minimum amount of care and supervision and because they feel that there is not a sufficient price differential between different grades to warrant the trouble and expense of the more careful sorting required by the standard grades. Analysis of returns for three varieties show clearly that prices are in direct relation to grades. Table 28 shows that on an average No. 2 packs bring as high or higher prices than does the Unclassified pack, the exceptions being for Winesap of the 1924 crop and for York Imperial of the 1925 crop. This table shows that apples packed to meet the requirements of No. 1 grade generally have a distinct price advantage over the two other grades shown. Since Unclassified packs bring no better prices than No. 2 packs, all apples in such a pack that are better than No. 2 standard are normally sold for a price below the market for the grade in which they might be placed.

TABLE 28.—*Price per barrel received by Virginia growers for specified grades of three varieties of apples of 2½-inch size, crops of 1924–1926*

Variety and grade	Price received per barrel for reported sales		
	Crop of 1924	Crop of 1925	Crop of 1926
York Imperial:			
No. 1	$3.66	$3.42	$2.21
No. 2		2.48	1.94
Unclassified	3.03	3.40	1.95
Winesap:			
No. 1	4.08	5.32	2.85
No. 2	3.51	3.80	2.58
Unclassified	3.61	3.18	2.03
Yellow Newtown (Albemarle Pippin):			
No. 1	6.87	5.69	5.33
No. 2	5.61		4.74
Unclassified	4.60	4.06	3.54

MARKETING SERVICES AND CHARGES

Much attention at present is focused on the cost of getting apples from the grower to the consumer. In this region most growers are apparently satisfied with the marketing services offered, or at least they are indifferent to various efforts to improve such services. Growers generally seem to be satisfied that the intense competition (if large numbers of separate marketing agencies imply competition) means for them good service at low cost. Everyone knows that to

get apples to distant markets many different kinds of services must be rendered and that for such services a price must be paid.

The service of most immediate interest to the growers is that of the buyer or broker who assembles carloads at shipping point and supplies the domestic or foreign trade.

Apples represent from 80 to 90 per cent of the business done by the large number of the Cumberland-Shenandoah shippers from whom information was obtained. These shippers on an average do 83 per cent of their apple buying and selling during the fall and winter months, 14 per cent during the spring months, and 3 per cent during the summer months. Details of the apple business and the handling of farm and orchard supplies, and in some cases the handling of peaches, furnish employment throughout the year.

During the year's business many of these shippers perform extensive and beneficial services to many growers, for which they make certain charges that are more or less standardized. Under some conditions they require the grower to perform certain production and harvesting practices in order that the fruit may meet certain requirements. About 60 per cent of the interviewed shippers financed the growers in various ways, both during the growing season and during the time of harvesting or shipment. The usual amount of the advance made for delivery on consignment was $2 per barrel. When the shipper made advances during the production season he usually kept a careful check on the growers' practices to assure himself of the safety of his investment. However, most crop advances are made after the set of fruit has been determined in the spring. Usually no interest charge is made for the advance if the shipper handles the fruit. If the grower decides to market it through another organization he is usually permitted to do so, but he is sometimes required to pay, in addition to the principal of the loan, 25 cents per barrel for this privilege.

Although the shippers usually handle all grades and varieties of apples that the grower has to sell, it was found that in about 70 per cent of the cases the grower was required to put up a specified type of pack for each variety and wherever possible to provide an inspection certificate with each car loaded. Some shippers reserve the right to mark the packages with their own brands; other see no material benefit from using "brands." But the general consensus of opinion was that the contents of packages should be properly indicated and that markings according to the United States standard grades were sufficient.

Shippers perform a valuable service in finding markets and in establishing and maintaining contacts. Their business is to study the markets and to know what is wanted. Their bargaining for various varieties, grades, sizes, and types of packages is based on this knowledge for specific domestic and foreign markets. The shippers try to supply what is wanted and this effort may be largely responsible for the increasing practice among certain shippers of buying fruit on an orchard-run basis and then packing it at some centralized point, or of packing the fruit for growers and then selling it on the basis of grade. Such shippers frequently have central packing sheds, usually on railroad sidings, where they assume complete responsibility for grading and packing.

Shippers' charges for acting as growers' selling agents usually vary from 5 to 10 per cent on f. o. b. sales, or from 10 to 25 cents a barrel. Frequently domestic f. o. b. sales are made on the carload basis at a charge of $25 to $35. Certain charges stand out as approaching a standard for selling apples under different conditions. Thus, 7 per cent commission charges on foreign consignments seems to be frequently the charge for this service, whereas 10 per cent is the usual charge made on domestic consignments.

Items of expense to shippers for which these charges are made include office expenses, telegraph and telephone service, traveling and automobile expenses, and field expenses of the shippers' agents.

Although most shippers have a few growers with whom they trade year after year, in general they are active in soliciting business, which entails considerable expense. A shipper may solicit as many as 350 growers in a season, although the usual number varies from 20 to 50.

Then, too, less than half of the shippers from whom information was obtained had regular outlets for their apples; some sell through as many as 200 buyers, although the usual number ranged from 20 to 50. Soliciting orders from many buyers necessarily entails expenditures for telegrams, telephone calls, circulars, letters, and frequently personal visits.

Of the shippers from whom information was obtained, 70 per cent dealt only in carload quantities. In a few instances extra charges of 50 cents to $1 per barrel were made for handling less than carload lots, but usually shippers made no extra charges for handling less than carload quantities, since they could make up a carload from other sources.

In Table 29 are listed the usual charges per barrel for handling apples in car lots on consignment from Winchester, Va., to London, England.

TABLE 29.—*Charges per barrel for handling apples in car lots on consignment from Winchester, Va., to London, England*

Item	Charges per barrel	Percentage of total charge
	Dollars	*Per cent*
Domestic freight	0.54	21.5
Forwarding charges (average)	.02	.8
Insurance (average)	.04	1.6
Ocean freight (common stowage)	.90	35.8
Landing, wharfage, and cartage (average)	.60	23.9
Foreign agent's commission (5 per cent average)	.25	10.0
Domestic agent's commission (2 per cent)	.10	4.0
Miscellaneous (telegrams, postage, etc.)	.06	2.4
Total	2.51	100.0

Such items as forwarding charges, insurance, landing wharfage and commissions vary with different firms and with different cities. In addition to the regular charges enumerated, which amount approximately to $2.50 per barrel, there may be a cold-storage charge in the United States. This charge may vary in amount with the month of shipment, but on an average it will usually be between 50 and 60 cents per barrel. There may also be refrigeration during the time the apples are in transit by rail or by water, or both. For late summer shipments to foreign ports it is customary to ice cars and utilize

refrigerator stowage, especially for soft varieties, such as Jonathan and King David. The charge for refrigerating is indicated in Table 30. Ocean freight rates for ordinary stowage and for refrigerator stowage are given in Table 31.

TABLE 30—*Refrigeration rates per car of apples, 1929*

To—	From—											
	Wyoming, Del.	Shelburne Falls, Mass.	Lockport, N. Y.	Germantown, N. Y.	Riverton, N. J.	Chambersburg, Pa.	Hancock, Md.	Easton, Md.	Martinsburg, W. Va.	Winchester, Va.	Roanoke, Va.	Staunton, Va.
Boston, Mass	$50.00	$35.00	$45.00	$40.00	$42.50	$45.00	$50.00	$50.00	$55.00	$52.50	$52.50	$52.50
New York, N. Y	42.50	35.00	40.00	35.00	35.00	37.50	42.50	42.50	50.00	45.50	45.50	45.50
Washington, D. C	40.00	50.00	50.00	50.00	40.00	40.00	40.00	40.00	40.00	45.50	45.50	45.50
Pittsburgh, Pa	50.00	50.00	40.00	40.00	45.00	40.00	50.00	50.00	40.00	55.00	55.00	55.00
Cincinnati, Ohio	57.50	55.00	40.00	45.00	55.00	45.00	57.50	57.50	45.00	60.00	60.00	60.00
Louisville, Ky	65.00	60.00	55.00	60.00	65.00	55.00	65.00	65.00	50.00	65.00	65.00	65.00
St. Louis, Mo	67.50	60.00	50.00	55.00	60.00	55.00	67.50	67.50	50.00	70.00	70.00	70.00
Nashville, Tenn	67.50	70.00	65.00	65.00	70.00	60.00	67.50	67.50	60.00	65.00	65.00	65.00
Indianapolis, Ind	62.50	55.00	45.00	50.00	55.00	50.00	62.50	62.50	45.00	65.00	65.00	65.00
Cleveland, Ohio	57.50	55.00	40.00	45.00	55.00	45.00	57.50	57.50	40.00	60.00	60.00	60.00
Detroit, Mich	62.50	55.00	45.00	50.00	55.00	50.00	62.50	62.50	45.00	65.00	65.00	65.00
Chicago, Ill	67.50	60.00	50.00	55.00	60.00	55.00	67.50	67.50	50.00	70.00	70.00	70.00
Minneapolis, Minn	77.50	70.00	60.00	65.00	70.00	65.00	77.50	77.50	60.00	80.00	80.00	80.00
Kansas City, Mo	75.00	70.00	60.00	65.00	70.00	65.00	75.00	75.00	60.00	75.00	75.00	75.00
Dallas, Tex	90.00	80.00	70.00	75.00	80.00	75.00	90.00	90.00	70.00	85.00	85.00	85.00
New Orleans, La	80.00	80.00	75.00	75.00	80.00	75.00	80.00	80.00	70.00	75.00	75.00	75.00
Norfolk, Va	47.50	55.00	55.00	55.00	50.00	50.00	47.50	47.50	45.00	49.50	42.00	49.50
Richmond, Va	47.50	55.00	55.00	55.00	50.00	50.00	47.50	47.50	45.00	49.50	42.00	49.50
Atlanta, Ga	65.00	70.00	70.00	70.00	65.00	65.00	65.00	65.00	60.00	60.00	60.00	60.00
Tampa, Fla	75.00	80.00	80.00	80.00	75.00	75.00	75.00	75.00	70.00	70.00	70.00	70.00

To—	From—											
	Waynesville, N. C.	Cornelia, Ga.	Henderson, Ky.	Gallipolis, Ohio	Hillsboro, Ill.	Vincennes, Ind.	South Haven, Mich.	Waverly, Mo.	Springdale, Ark.	Grand Junction, Colo.	Wenatchee, Wash.	Watsonville, Calif.
Boston, Mass	$70.50	$71.50	$75.00	$55.00	$65.00	$60.00	$60.00	$75.00	$80.00	$85.00	$100.00	$100.00
New York, N. Y	63.50	65.00	67.50	50.00	60.00	55.00	55.00	70.00	75.00	80.00	95.00	95.00
Washington, D. C	63.50	65.00	67.50	50.00	60.00	55.00	55.00	70.00	75.00	80.00	95.00	95.00
Pittsburgh, Pa	75.00	85.00	62.50	45.00	55.00	50.00	50.00	65.00	70.00	75.00	90.00	90.00
Cincinnati, Ohio	75.00	72.50	50.00	40.00	50.00	45.00	45.00	55.00	60.00	75.00	90.00	90.00
Louisville, Ky	75.00	72.50	50.00	50.00	50.00	45.00	50.00	45.00	55.00	70.00	80.00	80.00
St. Louis, Mo	85.00	80.00	57.50	55.00	40.00	50.00	50.00	40.00	50.00	65.00	80.00	80.00
Nashville, Tenn	75.00	67.50	55.00	55.00	50.00	50.00	55.00	45.00	45.00	70.00	85.00	85.00
Indianapolis, Ind	80.00	80.00	57.50	45.00	45.00	40.00	40.00	50.00	60.00	70.00	85.00	85.00
Cleveland, Ohio	80.00	80.00	57.50	40.00	55.00	47.50	45.00	60.00	67.50	75.00	90.00	90.00
Detroit, Mich	85.00	85.00	65.00	45.00	45.00	45.00	40.00	65.00	70.00	75.00	90.00	90.00
Chicago, Ill	85.00	80.00	57.50	50.00	40.00	45.00	40.00	50.00	60.00	65.00	80.00	80.00
Minneapolis, Minn	95.00	90.00	72.50	60.00	50.00	55.00	55.00	60.00	60.00	65.00	75.00	80.00
Kansas City, Mo	90.00	87.50	67.50	60.00	45.00	55.00	55.00	40.00	50.00	60.00	75.00	75.00
Dallas, Tex	95.00	85.00	75.00	70.00	65.00	65.00	70.00	55.00	55.00	65.00	80.00	75.00
New Orleans, La	80.00	70.00	70.00	65.00	65.00	65.00	70.00	55.00	50.00	75.00	90.00	85.00
Norfolk, Va	56.50	59.00	65.00	55.00	65.00	60.00	60.00	65.00	75.00	80.00	95.00	95.00
Richmond, Va	56.50	59.00	65.00	55.00	65.00	60.00	60.00	65.00	75.00	80.00	95.00	95.00
Atlanta, Ga	65.00	49.50	65.00	60.00	65.00	65.00	65.00	60.00	60.00	80.00	95.00	95.00
Tampa, Fla	75.00	67.50	80.00	75.00	75.00	75.00	80.00	75.00	70.00	85.00	100.00	100.00

TABLE 31.—*Ocean freight rates for apples from New York to European countries*

Destination	Ordinary stowage			Refrigerator stowage		
	Barrel	Basket	Box	Barrel	Basket	Box
United Kingdom	$0.90	$0.45	$0.30	$1.40	$0.70	$0.50
Germany	1.10	.55	.375	1.75	.80	.70
Netherlands	1.00	.45	.35	1.75	.90	.75
Belgium	1.00	.45	.35	1.75	.90	.70
Havre-Bordeaux	1.10	-------	.40	1.75	-------	.75
Oslo	1.45	-------	.55	3.75	-------	1.55
Copenhagen	1.55	-------	.60	3.75	-------	1.25
Gothenburg	1.45	-------	.55	3.00	-------	1.00
Stockholm	1.45	-------	.55	3.00	-------	1.00
Seattle to South America	-------	-------	-------	-------	-------	1.67

The Cumberland-Shenandoah region enjoys advantages over certain other regions that produce the same varieties in the matter of transportation charges to important markets. For example, the freight rate per hundred pounds from Winchester, Va., to New York City is 34 cents, as compared with $1.50 from Wenatchee, Wash., to New York. (Table 32.) If the rates were in direct proportion to the distance, growers in the Cumberland-Shenandoah region would have even a greater advantage in selling in New York and other eastern markets. Western New York shippers have some advantage over Virginia shippers who sell in such markets as Pittsburgh, Cincinnati, and Louisville, even though the distance from western New York points to these markets is greater than from Virginia points. The freight rate from Lockport, N. Y., to Cincinnati is 33 cents per hundred pounds, as compared with 46 cents from Winchester, Va. (Table 32.)

TABLE 32.—*Carload freight rates on apples to different cities from various producing points, July 1, 1929*

(Fifth-class rates, except as shown. Minimum weight 24,000 pounds, except as noted. Rates in cents per 100 pounds [1])

To—	From—										
	Wyoming, Del.	Shelburne Falls, Mass.	Lockport, N. Y.	Germantown, N. Y.	Riverton, N. J.	Chambersburg, Pa.	Hancock, Md.	Easton, Md.	Martinsburg, W. Va.	Winchester, Va.	Roanoke, Va.
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Boston, Mass.	41.5	21.5	34.5	27.5	32.0	36.5	36.5	41.5	36.5	36.5	[2] 48.0
New York, N. Y.	31.0	25.5	32.0	19.0	19.5	32.0	33.0	31.0	33.0	34.0	[2] 41.5
Washington, D. C.	34.0	41.5	37.0	33.5	25.0	27.0	30.0	38.0	27.0	27.0	[2] 34.5
Pittsburgh, Pa.	34.0	36.5	26.5	36.5	32.0	31.0	31.0	40.5	31.0	31.0	[3] 40.5
Cincinnati, Ohio	49.0	49.0	33.0	49.0	47.0	46.0	46.0	49 0	46.0	46.0	[3] 44.0
Louisville, Ky.	56.5	56.5	36.5	56.5	54.5	53.5	53.5	56.5	53.5	53.5	[3] 44.0
St. Louis, Mo.	66.0	66.0	43.5	66.0	64.0	63.0	63.0	66.0	63.0	63.0	[3] 61.0
Nashville, Tenn.	[4] 82.0	[5] 70.5	51.0	[4] 85.0	[4] 98.0	[4] 78.0	[4] 68.0	[4] 82.0	[4] 78.0	[4] 78.0	[6] 56.5
Indianapolis, Ind.	52.5	52.5	64.5	52.5	50.5	49.5	49.5	52.5	49.5	49.5	[3] 47.5
Cleveland, Ohio	40.5	40.0	25.0	40.0	38.0	37.0	37.0	40.5	37.0	37.0	[3] 40.5
Detroit, Mich.	44.0	44.0	26.5	44.0	42.0	41.0	41.0	44.0	41.0	41.0	[3] 41.0
Chicago, Ill.	56.5	56.5	34.0	56.5	[4] 54.5	53.5	53.5	56.5	53.5	53.5	[3] 51.5
Minneapolis, Minn.	78.0	91.0	60.0	78.0	76.0	75.0	75.0	76.0	75.0	75.0	[7] 83.5
Kansas City, Mo.	98.0	98.0	75.5	98.0	96.0	95.0	95.0	96.0	95.0	95.0	[8] 117.0
Dallas, Tex.	[6] 116.0	[6] 122.0	[6] 106.0	[6] 116.0	[6] 113.0	[6] 110.0	110.0	[6] 116.0	[6] 110.0	[6] 110.0	[6] 102.0
New Orleans, La.	[4] 98.0	[4] 106.0	63.0	[4] 106.0	[4] 112.0	[4] 98.0	[4] 102.0	[4] 98.0	[4] 95.0	[4] 95.0	[6] 71.0
Norfolk, Va.	27.0	41.5	40.5	36.5	34.0	38.0	40.5	27.0	38.0	[6] 31.0	[3] 31.0
Richmond, Va.	41.5	41.5	40.5	36.5	34.0	[3] 34.0	37.5	41.5	34.0	[6] 28.5	[6] 28.5
Atlanta, Ga.	[6] 68.0	[6] 70.0	[6] 83.0	[6] 70.0	[6] 68.0	[6] 65.0	[6] 68.0	[6] 68.0	[6] 65.0	[6] 65.0	[6] 49.5
Tampa, Fla.	[6] 84.5	[6] 87.5	[4] 105.5	[6] 86.5	[6] 84.5	[6] 81.5	[6] 84.5	[6] 84.5	[6] 81.5	[6] 81.5	[3] 86.0

See footnotes at end of table.

TABLE 32.—*Carload freight rates on apples to different cities from various producing points, July 1, 1929*—Continued

To—	From— Staunton, Va.	Waynesville, N. C.	Cornelia, Ga.	Henderson, Ky.	Galipolis, Ohio	Hillsboro, Ill.	Vincennes, Ind.	South Haven, Mich.	Waverly, Mo.	Springdale, Ark.	Grand Junction, Colo.
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Boston, Mass	[6] 44.0	[6] 79.5	[6] 66.0	65.5	49.5	68.5	61.0	57.0	[9] 101.0	[6] 101.0	[10] 150.0
New York, N. Y	[6] 40.5	[6] 59.0	[6] 59.0	62.5	46.5	65.5	58.0	54.0	[9] 98.0	[6] 97.0	[10] 150.0
Washington, D. C	[6] 28.5	[6] 57.0	[6] 52.5	59.5	43.5	62.5	55.0	51.0	[9] 96.0	[6] 94.0	[10] 150.0
Pittsburgh, Pa	40.5	[3] 76.0	[3] 68.0	40.0	27.0	42.0	36.0	33.0	[9] 76.5	[6] 81.0	[10] 140.5
Cincinnati, Ohio	46.0	[3] 59.0	[3] 66.0	25.5	25.0	29.0	25.0	29.0	[9] 63.5	[6] 65.0	[10] 129.0
Louisville, Ky	53.5	[6] 42.5	[3] 65.0	21.0	30.5	25.5	22.5	32.0	[9] 61.0	[6] 63.0	[10] 129.0
St. Louis, Mo	63.0	[11] 60.0	[12] 75.0	26.5	32.5	[5] 19.5	23.0	34.5	[3] 33.5	[6] 51.0	[10] 105.0
Nashville, Tenn	[6] 65.0	[6] 38.5	[3] 55.0	[4] 26.0	[4] 58.0	[4] 50.0	[4] 44.0	[4] 60.0	[9] 70.5	[6] 66.0	[10] 150.0
Indianapolis, Ind	49.5	[3] 68.0	[3] 73.0	26.5	28.0	25.5	20.5	27.0	[9] 60.5	[6] 65.0	[10] 126.5
Cleveland, Ohio	40.5	[3] 73.0	[3] 79.0	37.0	27.0	34.0	32.0	29.0	[9] 69.5	[6] 75.0	[10] 135.5
Detroit, Mich	41.0	[3] 75.0	[3] 81.0	37.0	28.5	33.0	32.0	25.5	[9] 68.5	[6] 75.0	[10] 133.0
Chicago, Ill	53.5	[3] 76.0	[3] 81.0	31.0	33.0	[4] 26.5	26.5	22.0	[3] 42.0	[6] 65.0	[10] 113.0
Minneapolis, Minn	[6] 73.0	[13] 82.0	[13] 89.0	65.5	60.0	57.0	52.0	48.0	[6] 43.0	[6] 71.0	[10] 113.0
Kansas City, Mo	95.0	[3] 86.5	[3] 82.5	58.5	67.5	51.5	55.0	66.5	[6] 14.0	[6] 42.0	[10] 90.0
Dallas, Tex	[6] 104.0	[6] 97.0	[6] 88.0	[4] 104.0	[6] 97.0	[6] 79.0	[6] 81.0	[6] 97.0	[6] 70.0	[6] 51.0	[10] 113.0
New Orleans, La	[6] 77.0	[6] 45.0	[6] 45.0	74.0	[4] 92.0	[4] 76.0	[4] 76.0	[4] 92.0	[6] 69.5	[6] 76.0	[10] 113.0
Norfolk, Va	[14]	[6] 38.5	[3] 64.0	62.5	40.5	62.5	55.0	51.0	[9] 95.0	[6] 101.0	[16] 150.0
Richmond, Va	[14]	[3] 58.0	[3] 62.0	62.5	40.5	62.5	28.5	51.0	[9] 95.0	[6] 101.0	[10] 150.0
Atlanta, Ga	[6] 57.0	[3] 44.0	[6] 14.0	59.0	[4] 69.0	[4] 71.0	[4] 65.0	[4] 78.0	[9] 102.5	[6] 78.0	[10] 150.0
Tampa, Fla	90.0	[3] 78.0	[3] 72.0	94.0	[4] 101.0	[4] 103.0	[4] 98.0	[4] 112.0	[15] 114.0	[16] 110.5	[17] 171.5

[1] Freight and refrigeration rates shown in this bulletin are presented merely as a matter of information. They are subject to frequent change and can have no standing in controversies with carriers regarding transportation charges. The commodity rate from Wenatchee, Wash., and Watsonville, Calif., $1.50 per 100 pounds to all cities enumerated in the above table. Minimum carload weights: Cars under 32 by 9 feet, 31,000 pounds; cars 32 by 9 feet and over, 35,000 pounds.
[2] Commodity rates. Not applicable when in boxes.
[3] Class rates.
[4] Sixth class.
[5] Minimum weight, 30,000 pounds. Fifth class.
[6] Commodity rates.
[7] Cincinnati combination. Class rates.
[8] St. Louis-Jacksonville combination. Class rates.
[9] St. Louis combination.
[10] Commodity rates. Minimum weight, 30,000 pounds in packages.
[11] Commodity rates. Memphis combination.
[12] Minimum weight, 30,000 pounds. Combination rates.
[13] Combination rates. St. Louis-Jacksonville combination.
[14] Intrastate tariff not on file with Interstate Commerce Commission.
[15] St. Louis-Jacksonville combination.
[16] Jacksonville combination. Commodity rates.
[17] Jacksonville combination. Commodity rates. Minimum weight, 30,000 pounds in packages.

Among wholesale dealers in 17 Pennsylvania cities the gross margin for handling apples in 1926 varied from 10 to 30 per cent. In actual money the gross margin varied from 25 cents to $1.50 per barrel, and was frequently 50 cents, 75 cents, or $1. The usual margins obtained on bushel-basket and box stock are 25 and 50 cents.

Many dealers reported that they frequently receive a car of apples of such grade that it can be moved at only a very small margin, if any. Such instances mean the increasing of the margin on other cars of better quality. Nearly every dealer spoke of a lack of definite standards among the growers of this region with respect to grade and size, and expressed the opinion that poorly graded apples are not only a direct cause of slow market demand but an absolute hindrance to handling apples on lower margins. They feel that the growers would improve the wholesaler's handling problems if the contents of the various packages were more accurately specified; especially is this true of the barrel pack.

METHODS OF SALE

The grower has the option of various methods in selling his crop. He may sell for cash at his shipping point to buyers who may be either local dealers or representatives of city dealers. He may sell to large merchandising organizations with local branches, or he may have such an organization act as a selling agency for him. The grower may consign his fruit to a city dealer, who charges a certain percentage of the sale price for his services in selling. Growers in certain sections of the Cumberland-Shenandoah region who are advantageously situated with respect to local markets have found it profitable to haul their fruit to market by motor truck and to sell to wholesalers, to retailers, or to consumers direct. Roadside markets have afforded farmers in certain locations a method of disposing of some of their fruit.

Apparently there has been an increase during late years in the practice of growers selling fruit on the trees to buyers who harvest and pack the apples. Reasons why some growers prefer this method of selling are: They would require financial assistance in harvesting, and therefore prefer to let the buyer harvest and pack the apples; buyers are becoming more discriminating than formerly in regard to grades and are more experienced in grading requirements than is the average grower; grading laws in some States require that the package be marked as to contents in a certain way, and the grower often prefers to have the buyer assume this responsibility. Selling on the trees involves an element of speculation on the part of both buyer and seller, since such sales are usually made a month or more before harvest time. The quality of the fruit and condition of the market at harvest can not, therefore, be accurately known. On an average, the buyer's wider experience and knowledge of market conditions gives him some advantage over the grower in bargaining for sale of fruit on the trees. In many instances sales of apples on the trees have brought the grower smaller net returns than he would have received had he harvested and packed the fruit.

Cooperative selling by growers has not been developed to any great extent in this region, although several small cooperative associations are in operation.

The buyers, sales agencies, or growers who ship apples sell them on an f. o. b. shipping-point basis or consign them to a dealer in some market to sell on a commission basis as the shipper's agent. In an f. o. b. sale the price is for the fruit loaded on the car at shipping point, and the responsibility for damage or deterioration that may occur in transit is with the buyer.

F. o. b. sales have certain advantages for growers over consignments. Fewer risks are involved in an f. o. b. sale. The shipper knows the price he is to receive when the shipment is made. In consigning, the shipper does not know what the condition of the market will be when his fruit arrives. If through communication with his agent he finds the market unsatisfactory when his fruit arrives, he may divert his shipment to another market or may store it. The costs of transportation, commission for selling in the market, and often other incidental expenses must be paid by the shipper when the fruit is consigned.

In years when the production is large, shippers find it more difficult to sell on an f. o. b. basis, and a larger part of the shipments are consigned than in years of smaller production. For example, only 45

per cent of the large crop of 1926 from this region was sold f. o. b., as compared with about 66 per cent and about 77 per cent, respectively of the crops of 1925 and 1924. (Table 33.) In general, it is much easier to sell high-quality fruit on an f. o. b. basis than poor-quality fruit. Shippers' records for the three years show that the greater part of the fruit that they classified as No. 1 was sold f. o. b. A large part of the export shipments for the 3-year period was consigned. (Table 33.)

TABLE 33.—*Proportional distribution of No. 1 and Unclassified apples sold f. o. b. and consigned, by destination and crop year*

Method of sale and destination	Grade	Crop of 1924	Crop of 1925	Crop of 1926
F. o. b.:		*Per cent*	*Per cent*	*Per cent*
Domestic markets	No. 1	48.5	27.4	19.0
	Unclassified	14.6	17.5	2.7
Foreign markets	No. 1	9.6	12.0	13.4
	Unclassified	4.1	8.7	9.9
Total		76.8	65.6	45.0
Consignment:				
Domestic markets	No. 1	3.7	3.7	5.0
	Unclassified	1.5	.4	2.3
Foreign markets	No. 1	5.4	2.0	26.1
	Unclassified	12.6	28.3	21.6
Total		23.2	34.4	55.0

Prices to growers at shipping point have varied considerably with the method of sale. A comparison of these prices received for No. 1 apples of 2¼ inch minimum diameter in the 1926 season shows that f. o. b. shipments of York Imperial to domestic markets averaged $2.34 per barrel, as compared with $1.94 for consignments. Foreign shipments of the same grade and size of this variety returned $2.46 if f. o. b. sales and $2.04 if consignments. (Table 34.) Most other varieties on which figures were obtained show similar comparisons, although there were a few exceptions. For example, domestic f. o. b. sales of Ben Davis in 1926 averaged $2 per barrel, as compared with $2.41 on domestic consignments.

TABLE 34.—*Prices per barrel to grower, shipping-point basis, for No. 1 apples, 2¼ inches minimum diameter, sold in domestic and foreign markets under different methods of sale, crop of 1926*

Variety	F. o. b. shipments		Consignments	
	Domestic	Foreign	Domestic	Foreign
Ben Davis	$2.00	$2.69	$2.41	$1.77
Stayman Winesap	2.25	2.40	1.41	1.54
Winesap	3.10	2.87	2.72	1.79
Yellow Newtown (Albemarle Pippin)	5.11	3.07	4.09	3.30
York Imperial	2.34	2.46	1.94	2.04

In this comparison of prices received under these two methods of sale it should be kept in mind that, in spite of the fact that the records of shippers show that the shipments on which the comparison was made were of the same grade and size of apples, there may have been

differences which could not be described in the records. Variations in such factors as condition and color of fruit would make the fruit that was consigned less desirable and might account for some of the differences in the returns on f. o. b. and consigned fruit.

Apples that are not of the best quality and that can not be readily sold on an f. o. b. basis are necessarily consigned. The average quality of consignments is undoubtedly lower than that of apples sold on an f. o. b. basis. The grower who produces apples of a high quality is in a position to sell a larger part of his crop on an f. o. b. basis than is the grower whose crop is of inferior quality.

CONTAINERS

The barrel is the principal package used in the Cumberland-Shenandoah region, but growers and shippers are responding to the increasing preference of the domestic retail trade for the basket pack. A very small quantity of the choicest fruit is packed in boxes, but most of the fruit does not carry enough "finish" to warrant the use of the box pack.

Of nearly 1,700,000 bushels sold in containers by the Virginia dealers reporting sales in 1924–1926, only 0.3 per cent was packed in boxes. Less than 4 per cent was sold in baskets, and the remainder, about 96 per cent, was packed in standard barrels. The distribution of the pack of the eight principal varieties is shown in Table 35. Basket packing has been more widely practiced since these figures were obtained.

TABLE 35.—*Average sales of eight principal varieties of Virginia apples in barrels, baskets, and boxes, by dealers reporting, crops of 1924–1926*

Variety	In barrels		In baskets		In boxes		Total	
	1,000 bushels	*Per cent*	*1,000 bushels*	*Per cent*	*1,000 bushels*	*Per cent*	*1,000 bushels*	*Per cent*
York Imperial	757.7	98.3	12.2	1.6	0.8	0.1	770.7	100
Winesap	256.9	95.0	10.0	3.7	3.4	1.3	270.3	100
Stayman Winesap	160.3	89.6	17.6	9.8	1.0	.6	178.9	100
Yellow Newtown	131.7	98.1	2.5	1.8	.1	.1	134.3	100
Ben Davis	121.0	99.7	.4	.3			121.4	100
Arkansas (Mammoth Black Twig)	98.0	92.7	7.7	7.3			105.7	100
Grimes Golden	71.8	97.2	2.1	2.8			73.9	100
Delicious	21.4	64.8	11.6	35.2			33.0	100
Total	1,618.8	95.9	64.1	3.8	5.3	.3	1,688.2	100

A considerable proportion of the crop produced is not packed at all, but is sent to the processing plants for canning or for pressing, as indicated by the record of West Virginia growers in seven years with nine varieties. (Table 36.)

TABLE 36.—*Average percentage of crop of nine varieties of apples sold in package and in bulk by 13 West Virginia growers for seven years, 1920 and 1922–1927*

Variety	In packages	In bulk		Variety	In packages	In bulk	
		Canner	For cider			Canner	For cider
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
York Imperial	52.98	36.96	10.06	Grimes Golden	69.02	20.39	10.59
Winesap	63.00	22.20	14.80	Delicious	84.07	11.54	4.39
Stayman Winesap	70.78	25.66	3.56	Gano	72.58	19.72	7.70
Ben Davis	45.35	43.99	10.66	Northwestern Greening	72.70	23.66	3.64
Arkansas (Mammoth Black Twig)	73.83	24.92	1.25				

From the growers' standpoint the advantage of the basket pack, preferred by the retailers reporting, is not clear at all times. Three bushel baskets are considered the equivalent of one barrel for most purposes; but in spite of greater cost for the baskets and greater labor in packing them, three baskets can not always be sold for more money than a barrel. Table 37 shows comparable returns for barrel and basket packs of six varieties sold in the domestic trade in three seasons by Virginia growers.

TABLE 37.—*Returns to Virginia growers, per barrel, for six varieties of apples packed in barrels and in baskets,*[1] *crops of 1924–1926*

Variety	Return from sales, crop of 1924—		Return from sales, crop of 1925—		Return from sales, crop of 1926—	
	In barrels	In baskets	In barrels	In baskets	In barrels	In baskets
York Imperial	$3.45	$2.91	$3.30	$3.12	$2.14	$1.74
Winesap	4.41	5.28	4.33	5.67	2.93	3.60
Stayman Winesap	4.02	4.41	3.94	4.23	2.19	2.16
Yellow Newtown (Albemarle Pippin)	6.00		4.57	5.22	4.18	3.33
Grimes Golden	3.44	3.00	3.61	4.32	2.50	2.31
Delicious	4.04	5.97	3.97	5.61	3.42	3.51

[1] In stating the return for apples sold in baskets, 3 baskets were considered the equivalent of 1 barrel.

Delicious and Winesap showed distinct advantage in favor of sales in the basket pack, whereas basket packs of Grimes Golden and Stayman Winesap brought higher prices under some conditions. Few Yellow Newtown are sold in baskets. The York Imperial when packed in baskets regularly returned less to Virginia growers than when packed in barrels.

Retailers reported the percentage of apples they bought in the different containers and in bulk. (Table 38.) The proportions taken reflect the usual source of supply and the practice of the growers there. Thus, Virginia retailers drawing principally from Virginia producers get barreled stock, whereas the Pennsylvania retailers get half their

stock in baskets, chiefly from Pennsylvania growers. The boxed apples reported are almost wholly western apples.

TABLE 38.—*Relative importance of containers as shown by purchases of retailers interviewed in Virginia, West Virginia, and Pennsylvania, season 1926–27*

State	Percentage of apples bought in—			
	Barrels	Baskets	Boxes	Bulk
	Per cent	*Per cent*	*Per cent*	*Per cent*
Virginia	66.0	14.6	5.8	13.6
West Virginia	34.1	49.9	6.0	10.0
Pennsylvania	14.0	50.0	30.0	6.0

SUMMARY

Marketing problems of apple producers in the Cumberland-Shenandoah region are of two general classes: (1) Problems arising from the nature and extent of apple production all over the country as well as within the region, and (2) problems of merchandising the crops in hand to the best advantage.

Competition between regions for the trade of the industrial consuming centers is keen. The varieties sold in largest volume in the city markets are grown successfully within the region. Producing conditions in the East as a whole are such that the eastern fruit as it comes to market is less attractive to city buyers than is western fruit as it comes to market. There are indications, however, that the unorganized producers in the East are suffering from a sense of inferiority, which can be gradually overcome by close attention to those points of orchard practice which result in a high percentage of unblemished fruit.

In merchandising apples grown in the region the chief present needs are strict and uniform grading and packing. Attention to extending the marketing season through storage and to developing the home market through catering to the customary preferences of the trade at the several markets promises some enhancement in net returns to growers.

Apples from the region are widely distributed over the eastern half of the United States, but apples from other regions are brought into the natural sales territory of the Cumberland-Shenandoah producers.

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QUALITY OF ALFALFA HAY IN RELATION TO CURING PRACTICE

By T. A. KIESSELBACH, *Agronomist*, and ARTHUR ANDERSON, *Assistant Agronomist, Nebraska Agricultural Experiment Station* [1]

CONTENTS

	Page
Introduction	1
Review of literature	2
Experimental work	3
Plan of curing tests	3
Determinations of initial basic leafiness and protein	7
Immediate raking compared with partial swath curing	8
Effect of overcuring in swath	9
Effect of size of windrow	9
Effect of turning windrow when partially cured	11
Relation of direction of windrow to curing	11
Direction of raking in relation to mower swath	12
Effect of type of rake	13
Experimental work—Continued.	
Time of cutting during day in relation to curing	13
Relation of cock curing to hay quality	14
Effect of turning hay exposed to external moisture	15
Effect of rain on protein content	16
Effect of artificial drying	16
Relation of leafiness of cured hay to protein content	17
Progressive loss of water from alfalfa in relation to curing practice	18
How moisture is lost from stems in curing	20
Discussion and conclusions	22
Literature cited	25

INTRODUCTION

The essential characteristics of high-grade alfalfa hay have been summarized by Parker (*8, p. 2*) [2] as consisting of "purity, a high percentage of leaves, clinging foliage, green color, and pliable stems." Other qualities that are stressed by the United States hay standards include freedom from mustiness and moldiness. It is commonly recognized that hay possessing the highest feed value and commanding the maximum market price conforms to the above specifications. The purpose of the investigations herein reported has been to determine the manner and extent to which the quality of the hay may be influenced by the mode of curing and to establish the basic principles of good curing practice.

[1] In cooperation with the Bureau of Plant Industry and the Bureau of Agricultural Economics, United States Department of Agriculture. Acknowledgments are made to A. J. Pieters, of the Office of Forage Crops and Diseases, Bureau of Plant Industry, for assistance in planning these investigations; to E. C. Parker, E. O. Pollock, and W. H. Hosterman, of the Division of Hay, Feed, and Seed, Bureau of Agricultural Economics, for personally inspecting and establishing the commercial grades of the hay; and to Supt. W. E. Lyness, J. O. Culbertson, and Austin Goth, of the Nebraska station farm, for assisting with the detailed labor connected with the experiments. The protein determinations were made under the direction of J. C. Russel, of the College of Agriculture, University of Nebraska. Acknowledgment is also given F. E. Mussehl for the unpublished results from feeding artificially dried alfalfa to chickens.

[2] Italic numbers in parentheses refer to Literature Cited, p. 25.

It was believed that these principles might be most effectively determined by contrasting the effects of a rather wide range of opposing conditions which may be subject to the control of the hay producer. As a result of this procedure a number of practices have been included which appear self-evidently undesirable, but whose outcome serves to emphasize the advantages of more favorable treatments.

The various tests were designed to determine the effects of (1) immediate compared with delayed raking, (2) size of windrow, (3) turning the windrow after partial curing, (4) direction of windrow, (5) direction of raking with respect to direction of cutting, (6) type of rake, (7) time of cutting during the day, and (8) cocking immediately and after various degrees of curing. Supplementary studies were made of the effects of the speed of curing and of rain upon the protein content, and of the manner in which moisture escapes from the stems during the curing process.

One of the important considerations in regions where curing hay is subject to damage from rain is to follow a practice which shortens to a minimum the interval between cutting and storage and yet is conducive to good quality. Accordingly, the progressive rate of curing under various treatments was also determined.

REVIEW OF LITERATURE

The literature previous to 1926 on hay-curing practices has been reviewed by the writers (*5*) in another publication. A number of references appearing since that date are here included.

Steenbock, Hart, Elvehjem, and Kletzien (*11, p. 439*) conclude that—

> The antirachitic properties of hays are related to their exposure to sunlight. * * * Clover hay excessively weathered was reduced in antirachitic action as compared with hay less exposed to dew and rain. * * * There remains no question of the advisability of "making hay when the sun shines."

Mason (*7, p. 13*) with reference to artificially dried hay, says:

> It makes a beautiful bright-green hay, much greener than western sun-cured hay, and much superior in feeding value, as it runs from 18 to 23 per cent protein as against 14½ per cent in the western hay.

The Wisconsin Agricultural Experiment Station (*9, p. 42*) states:

> Accumulated experimental evidence secured this year by Messrs. Hart and Steenbock indicates that the antirachitic properties of plant tissues are directly related to their exposure to the sun. Hay cut without exposure to sunlight and cured in the dark away from sunlight has no antirachitic property.

Russell (*10, p. 296*) concludes that—

> Alfalfa leaves from plants dried by artificial heat, by the Mason process, were found to contain at least seven times as much vitamin A as the leaves from hay that was cured in the field so that the greater part of its green color was lost.
>
> The sample which contained the larger amount of vitamin A was green as compared with the brownish green color of the field-cured sample.
>
> The leaves of the artificially cured plants contained only a small amount of the antirachitic vitamin.
>
> When the alfalfa was dried in the sun, without exposure to dew or rain, there was an increase in the antirachitic potency of the leaves, but it was accompanied by a decrease in vitamin A content.

The Michigan Agricultural Experiment Station (*1, p. 356–357*) reports:

Special investigations were begun regarding methods of curing hay. It was shown that hay cured in loose windrows dried down much more uniformly than where it was partially cured in the swath. When cured in the windrows, the leaves and stems lose moisture at about the same rate while the hay cured in the swath shows a divergence of as much as 10 per cent in moisture content between the leaf and stem, the leaves drying rapidly while the stems retain much moisture. This condition causes loss of leaf and often times spoilage in the mow.

Cox and Megee (*2, p. 46–48*) state:

In curing alfalfa, follow a method that will conserve the leaves and produce hay of bright green color. To do this, it is necessary that the leaves and stems dry out so that the per cent of moisture will be about the same in each. When alfalfa is cured in the swath, the leaves lose their moisture very rapidly, while the stems lose their moisture very slowly, resulting in brittle, crumbling leaves that shatter off very easily while the stems are still comparatively green. This method produces a hay of poor quality. Heavy yields of hay are difficult to cure in the swath. The upper part will dry out and leaves shatter easily while the lower part will be very slow to lose its moisture.

Curing in the windrow allows the stems and leaves to dry down together. When the hay is heavy, the windrows may be turned, greatly facilitating the curing. After a rain, the windrows may be turned with the side-delivery rake and curing hastened. In using the side-delivery hayrake, the hay may be raked immediately after cutting, or may be allowed to remain in the swath [3] two or three hours before raking. The hay should be raked into a loose, open swath before the leaves have lost sufficient moisture to become brittle. The left-hand side-delivery rake is advantageous in that it operates in the opposite direction to the course of the mower. The left-hand rake works against the tops of the plants instead of the newly cut butts, throwing a majority of the leafy tops toward the center of the windrow, thus aiding in the conservation of the leaves through better curing.

The Iowa Agricultural Experiment Station (*3, p. 29*) reports:

The best quality of alfalfa hay is secured normally by windrowing shortly after it has been cut. The process may be hastened a little by permitting the hay partially to dry out in swath before windrowing.

Experiments show that the leaves help "pump" water out of the stems. This principle is made more effective when the hay is windrowed. The environment naturally plays an important rôle. To standardize practices, the evaporating environment has been given particular attention. Aeration is important in hay storage.

Parker (*8, p. 8*) has stated:

Essential points to consider are (1) facilitating rapid evaporation of a large part of the moisture in the newly mown hay by exposing it to sun and wind in the swath, where the rate of evaporation is faster than in the windrow, bunch, or cock, and (2) performing the operations of raking and windrowing while the hay is tough and the leaves are not easily shattered.

The rapid evaporation of moisture and the preservation of leafiness and color are jointly accomplished in the most practical manner when the hay is wilted for a short time in the swath and then either windrowed with the side-delivery rake or cocked to complete the evaporation of moisture to that degree where the hay may be stored or baled. * * *

EXPERIMENTAL WORK

PLAN OF CURING TESTS

CHARACTER OF PLOTS

A comparatively uniform 12-acre alfalfa meadow located on the experiment station farm at Lincoln, Nebr., was used for these investigations. This meadow was in its prime, yielding at the rate of 4.5 tons per acre in 1928 when these tests were made.

[3] "Windrows" evidently meant.

A large number of curing practices were compared. (Table 1.) Forty-eight plots (fig. 1) approximately one-fifteenth of an acre in size were required for each test. By dividing the meadow into three series and harvesting those successively at approximately weekly intervals during each of three crops, it was possible to undertake nine duplicate tests. Because of rain interference or other unavoidable factors only six of these, or portions thereof, materialized satisfactorily for inclusion in this report. Although the first three tests differed somewhat with respect to the maturity of the alfalfa when cut, the succeeding tests were harvested at approximately the half-bloom stage.

48	42	36	30	24	18	12	6
47	41	35	29	23	17	11	5
46	40	34	28	22	16	10	4
45	39	33	27	21	15	9	3
44	38	32	26	20	14	8	2
43	37	31	25	19	13	7	1

FIGURE 1.—Relative location of the alfalfa plots, experiment station farm, Lincoln, Nebr.

TABLE 1.—*Treatments applied to alfalfa during the curing process, and arrangement of the plots*

Treatment	Plot numbers raked with—	
	Side-delivery rake	Sulky rake
Hay cut at 9 a. m.:		
Raked immediately after cutting into—		
Small windrows	1	8
Medium windrows	2	9
Large windrows	3	10
Medium windrows, turned after 4 hours	4	11
Medium windrows, placed in small cocks after 4 hours	5	12
Medium windrows, placed at once in small cocks	6	----
Medium windrows, placed at once in large cocks	7	----
Raked 4 hours after cutting into—		
Small windrows	13	20
Medium windrows	14	21
Large windrows	15	22
Medium windrows, turned after 4 hours	16	23
Medium windrows, placed in small cocks after 4 hours	17	24
Medium windrows, placed at once in small cocks	18	----
Medium windrows, placed at once in large cocks	19	----
Medium windrows (extending from north to south)	44	45
Medium windrows (raked opposite to direction of mowing)	39	42
Medium windrows (raked with direction of mowing)	40	41
Medium windrows (raked crosswise to direction of mowing)	43	46
Raked 8 hours after cutting into—		
Medium windrows	25	28
Medium windrows, placed at once in small cocks	26	----
Medium windrows, placed at once in large cocks	27	----
Raked 24 hours after cutting into—		
Medium windrows	29	32
Medium windrows, placed at once in small cocks	30	----
Medium windrows, placed at once in large cocks	31	----
Raked when field cured into medium windrows	33	34
Raked when overcured into—		
Medium windrows (in morning when damp)	35	36
Medium windrows (in afternoon when dry)	37	38
Hay cut at 1 p. m.: Raked 4 hours after cutting into medium windrows	47	----
Hay cut at 5 p. m.: Raked 16 hours after cutting into medium windrows	48	----

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ERRATUM

U. S. Department of Agriculture. Technical Bulletin 235. "Quality of Alfalfa Hay in Relation to Curing Practice."

Page 3, Footnote 3. Reference number to this footnote should follow the words "into a loose, open swath," in line 23 instead of the word swath in line 22.

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Hay cut at 5 p. m.: Raked 16 hours

MOWING, RAKING, AND COCKING

The area comprised within each test was approximately 225 by 800 feet. (Fig. 2.) Mowing (from east to west) was started at 8 a. m., and two hours were usually required to cut over this area with two 5-foot machines. All raking was done with either a standard left-hand side-delivery rake or a sulky rake. Hay raked immediately after cutting was usually in the windrow within 15 minutes. The first operations on the first day of any test were therefore completed shortly after 10 o'clock. For the purpose of simplification in compiling the data, all tests are considered as having begun at 9 a. m., which was midway during this period of getting the tests under way.

FIGURE 2.—General view of the alfalfa meadow in which the hay-curing tests were made. This field produced at the rate of 4.5 tons of cured hay per acre during the season of 1928. In the foreground are shown small-sized cocks made at the rate of 120 per acre. At the distant right are large cocks, of which there were 60 per acre. In the background various combinations of swath and windrow curing are being compared

Except as otherwise stated, the side-delivery rake followed the direction of mowing, and the sulky rake went crosswise to the swath. (Fig. 3.) This procedure was followed in order to maintain windrows comparable in size and direction, thus making possible direct comparisons between the two types of rakes. Studies conducted in connection with these tests have indicated that direction of windrows or direction of raking with respect to the mower swath were not factors in the rate of curing or in the quality of hay resulting. The windrows were approximately 85 feet long with 2, 4, and 8 mower swaths in the small, medium, and large windrows, respectively. Except in the size-of-windrow comparison, however, all windrows contained 4 mower swaths or their equivalent. Thus the maintaining of such procedure with both types of rakes permits a direct comparison between type of rake and quality of hay produced and the time required for curing.

In the case of the cocked hay, 4 small and 2 large cocks were made from each medium-sized windrow, or 8 and 4 cocks per plot. In making these cocks the hay was forked over by hand and the cocks well rounded as a protection against the weather.

At the time the hay on each plot was considered sufficiently cured for storage it was forked over twice. Such treatment was intended to mix the hay for sampling and to simulate the amount of handling that hay receives under average farm conditions. Hay with a moisture content of 25 per cent was considered field cured. Since there was no way of determining the moisture content in the field, it was necessary to rely on observation and experience in deciding when the hay had reached a cured condition. Moisture determinations that followed revealed the true moisture content.

SAMPLING FOR MOISTURE AND QUALITY DETERMINATIONS

At the time the hay in each plot was pronounced field cured, three composite samples of approximately the indicated weights were taken as follows: (1) A 5-pound sample, which was immediately run

FIGURE 3.—Standard types of hayrake used in these curing studies. At the right is a sulky rake; at the left, a side-delivery rake

through a hand feed cutter and reduced to a 500-gram sample for moisture determination; (2) a 300-gram sample for relative leaf and stem determination on a moisture-free basis; and (3) a 7-pound sample stored in a 15 by 17 by 19 inch carton for official grading.

The samples selected for moisture determination were cut into lengths of approximately one-half inch by means of a hand feed cutter to facilitate mixing and reducing. The time occupied by this entire operation of sampling and reduction seldom exceeded 15 minutes. During this time the samples were protected from undue exposure.

The box samples from any one crop were graded according to the official United States hay standards soon after completion of the third test of each crop. In addition to the factors ordinarily considered in grading hay, the texture or condition of the stems was scored numerically as follows: 1, Pliable; 2, medium hard and brittle; 3, hard and brittle; and 4, very hard and brittle.

A rough separation was first made of the leaf-stem samples. This was followed later by a more careful separation of the stems from the leaves. After moisture-free weights had been taken, the leaves and stems were mixed, ground, and reduced for protein determinations. The percentage of leaves as determined in these separations was used as the leafiness factor in reporting the final grade.

The grade of hay as reported in the tables is based on the average of grade factors given for the individual tests. Where a sample grade resulted in individual tests, the frequency of such occurrence is reported.

In addition to the sampling already mentioned, composite samples approximating 3 pounds of cured hay were taken at stated intervals (9 a. m., and 1 and 5 p. m.) from a number of plots during the first three days of four different tests, in order to measure comparative curing rates. These samples were run through a hand feed cutter in the field and reduced to 500 grams for moisture determination.

PRESENTATION OF DATA

Because of the variability of weather conditions, the inability to determine the moisture content of the hay in the field, and the limitations of the sampling methods, it seems desirable to base conclusions and interpretations with reference to the field-curing studies on average results rather than on individual tests. Experiments were started on June 6, 13, and 18; July 11, 16, and 23; and August 14, 21, and 27. Because of excessive rain in the case of tests begun on June 6 and 18 and July 16, these have not been included in the general averages. Comparable results pertaining to direction of raking with respect to mower swath were secured only for the tests beginning July 23 and August 14 and 21.

DETERMINATIONS OF INITIAL BASIC LEAFINESS AND PROTEIN

In order to study the effect of various curing practices upon the changes in quality due to the mechanical loss of leaves, it seemed essential to have an initial determination of leafiness, free from shattering, to serve as a basis for comparisons. Accordingly, two representative samples were collected at random for analysis at the time of cutting. One of these was immediately dried in the drying oven for moisture determination and later analysis. The other was spread out thin on a canvas in the hay barn for slow curing and freedom from leaf loss. The average results for both types of samples are reported in Table 2. The samples that cured slowly in the shade averaged 48 per cent leaves and 18.8 per cent protein, while those cured rapidly had 47.3 per cent leaves and 19 per cent protein.

TABLE 2.—*Quality and composition of alfalfa hay when cured under shelter to avoid losses from exposure*

[Average of six tests] [1]

Character of sample	Quality [2]						
	Stems	Color	Leaves	Protein			Grade
				Hay	Leaves	Stems	
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Slowly cured	1.9	72	48.0	18.8	----------	----------	1
Rapidly cured	----------	----------	47.3	19.0	27.49	11.39	1

[1] These are basic results from hay free from leaf shattering and weather damage. Any deviation therefrom in succeeding tables may be attributed to the field-curing procedure.

[2] All specific data in these quality notes in this and subsequent tables are averages for the duplicate tests. The commercial grade is based on the averages for the specific quality values. The color values are estimates. The percentage of leaves is on a moisture-free, total-weight basis. The numerical values of stems are straight averages which have the following significance: 1, Pliable; 2, medium hard and brittle; 3, hard and brittle; 4, very hard and brittle; L., leafy; Exl., extra leafy. S and a superior number following indicate the sample grade and its frequency.

Any reductions below these figures in the leafiness or protein content of the hay cured by various practices may be ascribed as due primarily to mechanical loss of leaves.

IMMEDIATE RAKING COMPARED WITH PARTIAL SWATH CURING

For comparison with immediate raking after cutting, alfalfa was retained in the swath before raking for periods of 4, 8, and 24 hours, and until completely cured. All comparisons were made with both side-delivery and sulky rakes, and medium-sized windrows containing four mower swaths were used throughout. The results, together with those pertaining to the question of overcuring discussed later, are summarized for the six duplicate tests in Table 3.

TABLE 3.—*Effect of immediate and delayed raking with side-delivery and sulky rakes upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of raking and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
		Per cent		*Per cent*	*Per cent*	*Per cent*	
Raked immediately after cutting:							
Side-delivery rake	82	22	2.3	53	40	17.4	2 L
Sulky rake	78	22	2.0	53	40	17.3	2 L
Average	80	22	2.2	53	40	17.3	2 L
Raked 4 hours after cutting:							
Side-delivery rake	60	24	2.2	61	40	17.1	1
Sulky rake	59	23	2.2	61	41	17.2	1
Average	60	24	2.2	61	41	17.2	1
Raked 8 hours after cutting:							
Side-delivery rake	54	25	2.0	59	41	17.4	2 L
Sulky rake	50	26	2.0	60	42	17.3	1
Average	52	26	2.0	60	42	17.4	1
Raked 24 hours after cutting:							
Side-delivery rake	54	25	2.0	60	40	17.0	1
Sulky rake	50	26	2.2	61	42	17.6	1
Average	52	26	2.1	61	41	17.3	1
Raked when field cured:							
Side-delivery rake	42	27	2.2	56	39	16.5	2
Sulky rake	42	26	2.0	56	38	16.4	2
Average	42	27	2.1	56	39	16.5	2
Raked when overcured:							
With dew on—							
Side-delivery rake	66	21	2.2	47	41	17.3	2 L
Sulky rake	66	21	2.2	45	43	17.6	2 L
Average	66	21	2.2	46	42	17.5	2 L
With dew off—							
Side-delivery rake	66	20	2.5	45	36	16.1	2
Sulky rake	66	20	2.3	43	35	16.2	2
Average	66	20	2.4	44	36	16.2	2

[1] For explanation of quality factors see Table 2, footnote 2.

The percentages of leaves and protein were not materially affected, whether raking was immediate or delayed for various intervals up to 24 hours. The color of the hay was considerably lowered, however, by immediate raking, which reduced the speed of drying and resulted in prolonged exposure in the field. Accordingly, the hay that was

FIGURE 4.—Combined swath and windrow curing. In the right foreground is shown a medium-sized windrow containing four mower swaths; at the left are small-sized windrows containing two mower swaths

raked immediately graded only No. 2, while all degrees of partial swath curing up to a 24-hour period resulted in grade No. 1. (Fig. 4.) Delay of raking until the alfalfa was fully cured in the swath shortened the period required but reduced the hay quality to grade No. 2 because of lessened color and leafiness.

EFFECT OF OVERCURING IN SWATH

In conjunction with the studies of partial swath curing reported in the preceding discussion, part of the forage was permitted to lie in the swath for an entire day after reaching the cured stage. Part of it was then raked in the forenoon while still tough with dew, and the other portion was raked after the dew had dried off. The effect of such overcuring, as shown in Table 3, was a decided loss in color; and when the raking was delayed until the dew had dried off, the leaf loss through shattering became pronounced. Both lots of hay that were overcured in the swath graded only No. 2 because of the undue field exposure.

EFFECT OF SIZE OF WINDROW

Hay was raked into small, medium, and large windrows with both types of rakes immediately and four hours after cutting. These windrows contained 2, 4, and 8 mower swaths, respectively. The

medium and large windrows were made with the side-delivery rake by rolling the hay over as necessary. The results are summarized in Table 4.

As an average for both types of rake, 64, 80, and 92 hours were required, respectively, for hay raked into small, medium, and large windrows immediately after cutting to reach a field-cured condition. In the parallel test where 4 hours of swath curing preceded windrowing, 50, 60, and 71 hours were required for the small, medium, and large windrows, respectively. The size of windrow did not materially influence the quality of hay in any respect. Marked differences in quality might result, however, from the retarded curing in large windrows in case of unfavorable weather.

TABLE 4.—*Effect of size of windrow and type of rake upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of raking, type of rake, and size of windrow	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:							
Side-delivery rake—		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Small windrow	64	24	2.0	54	41	17.4	2 L
Medium windrow	82	22	2.3	53	40	17.4	2 L
Large windrow	94	27	2.2	53	44	18.3	2 L
Average	80	24	2.2	53	42	17.7	2 L
Sulky rake—							
Small windrow	63	25	2.2	54	41	17.2	2 L
Medium windrow	78	22	2.0	53	40	17.3	2 L
Large windrow	90	27	2.0	53	43	18.4	2 L
Average	77	25	2.1	53	41	17.6	2 L
Raked 4 hours after cutting:							
Side-delivery rake—							
Small windrow	50	26	2.3	61	40	16.8	1
Medium windrow	60	24	2.2	61	40	17.1	1
Large windrow	71	23	2.2	63	40	17.3	1
Average	60	24	2.2	62	40	17.1	1
Sulky rake—							
Small windrow	50	24	2.2	60	40	17.1	1
Medium windrow	59	23	2.2	61	41	17.2	1
Large windrow	71	24	2.2	63	41	17.3	1
Average	60	24	2.2	61	41	17.2	1
Grand average							
Raked immediately after cutting:							
Small windrow	64	25	2.1	54	41	17.3	2 L
Medium windrow	80	22	2.2	53	40	17.4	2 L
Large windrow	92	27	2.1	53	44	18.4	2 L
Average	78	25	2.1	53	42	17.7	2 L
Raked 4 hours after cutting:							
Small windrow	50	25	2.3	61	40	16.9	1
Medium windrow	60	24	2.2	61	41	17.2	1
Large windrow	71	24	2.2	63	41	17.3	1
Average	60	24	2.2	62	41	17.1	1

[1] For explanation of quality factors see Table 2, footnote 2.

Owing perhaps to a longer exposure in the field, hay raked immediately after cutting retained but 53 or 54 per cent of its color, regardless of windrow size, and was therefore placed in grade 2. Hay raked four hours after cutting had 61 per cent or more color and was placed in grade 1.

There was no significant effect of the type of rake when windrows of equal size were compared except that in the case of the hay raked immediately after cutting the curing was somewhat more rapid when the sulky rake was used.

EFFECT OF TURNING WINDROW WHEN PARTIALLY CURED

The effect of turning the windrows four hours after raking was studied in connection with hay raked immediately after cutting and also with hay swath cured for four hours before raking. The results are summarized in Table 5. The tests were duplicated with both types of rake.

TABLE 5.—*Effect of turning of windrow after four hours of windrow curing upon quality of alfalfa hay and time required for curing*

[Average of 6 tests]

Time of raking and turning, and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:							
Side-delivery rake—		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Windrows turned after 4 hours	68	25	2.2	58	41	17.7	2 L
Windrows not turned	82	22	2.3	53	40	17.4	2 L
Sulky rake—							
Windrows turned after 4 hours	60	25	2.2	58	41	17.6	2 L
Windrows not turned	78	22	2.0	53	40	17.3	2 L
Average (both types of rake):							
Windrows turned after 4 hours	64	25	2.2	58	41	17.7	2 L
Windrows not turned	80	22	2.2	53	40	17.3	2 L
Raked 4 hours after cutting:							
Side-delivery rake—							
Windrows turned after 4 hours	56	24	2.2	58	40	17.3	2 L
Windrows not turned	60	24	2.2	61	40	17.1	1
Sulky rake—							
Windrows turned after 4 hours	55	25	2.2	59	41	17.6	2 L
Windrows not turned	59	23	2.2	61	41	17.2	1
Average (both types of rake):							
Windrows turned after 4 hours	56	25	2.2	59	41	17.5	2 L
Windrows not turned	60	24	2.2	61	41	17.2	1

[1] For explanation of quality factors see Table 2, footnote 2.

When both tests are averaged, turning the windrows of hay raked immediately after cutting reduced the length of the curing period by 16 hours. Where four hours of swath curing had preceded the raking, the turning of windrows shortened the curing period only four hours.

The color of the hay was somewhat benefited by turning the windrow in the case of immediate raking. This was probably due to a decided shortening of the curing period. There were no other significant variations as a result of the method of handling. In no case did turning the windrow raise the commercial grade.

RELATION OF DIRECTION OF WINDROW TO CURING

After four hours of swath curing, hay was raked with the side-delivery and sulky rakes into medium-sized windrows that extended from east to west and from north to south. The side-delivery rake followed the direction of mowing, and the sulky rake went crosswise to the mower swath in both instances. These tests were planned to determine the effect, if any, that the direction of windrow exposure might have on hay quality and curing rate. It was believed that such a difference in exposure with reference to prevailing wind and sun might affect the rate of drying. The results are summarized in Table 6.

TABLE 6.—*Effect of direction of windrow upon quality of alfalfa hay and time required for curing*

[Average of five tests]

Direction of windrow and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Windrows extending from east to west:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Side-delivery rake	61	23	2.2	63	40	16.9	1
Sulky rake	60	23	2.2	63	41	16.9	1
Average	60	23	2.2	63	41	16.9	1
Windrows extending from north to south:							
Side-delivery rake	59	25	2.2	62	44	17.5	1
Sulky rake	59	25	2.4	64	42	17.2	1
Average	59	25	2.3	63	43	17.4	1

[1] For explanation of quality factors see Table 2, footnote 2.

In an average of five duplicate tests there was no indication that the direction of windrow with either type of rake is a factor in rate of curing or in quality of the final product. All lots of hay produced graded No. 1.

DIRECTION OF RAKING IN RELATION TO MOWER SWATH

Tests were made to determine what effect raking at various directions with respect to the mower swath might have on rate of curing and quality. Hay was raked against the heads (following the mower), with the heads (opposite the mower), and crosswise to the swath, with both types of rake. The data are reported in Table 7. In an average of the three tests, beginning July 23 and August 14 and 21, there was practically no difference in the time required to reach a field-cured condition or in the quality factors of leafiness and protein content in response either to direction of raking with respect to the mower swath or to the type of rake. The color percentage ranged from 60 to 67, but the variation bore no apparent relation to the method of curing. All lots of hay graded No. 1.

TABLE 7.—*Effect of direction of raking with respect to mower swath upon quality of alfalfa hay and time required for curing*

[Average of three tests]

Direction of raking and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Side-delivery rake:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
With direction of mowing	57	22	2	60	43	17.1	1
Opposite to direction of mowing	57	19	2	65	44	17.8	1
Crosswise to the mowing	58	20	2	67	44	17.7	1
Sulky rake:							
With direction of mowing	57	22	2	63	44	17.5	1
Opposite to direction of mowing	57	20	2	60	43	17.6	1
Crosswise to the mowing	58	19	2	60	43	17.1	1

[1] For explanation of quality factors see Table 2, footnote 2.

EFFECT OF TYPE OF RAKE

It will have been noted that all of the curing practices reported in Tables 3 to 7 were conducted in duplicate with the two standard types of rake—side delivery and sulky. With few exceptions it made no important difference which rake was used. In a number of cases somewhat less time was required for hay to cure when windrowed with the sulky rake. This may have been due to the fact that the sulky rake left the windrow somewhat wider than, and therefore not quite so deep as, the windrow made by the side-delivery rake.

In general both types of rake gave practically equal results with respect to moisture content, color, leafiness, and protein percentage of the hay when equal-sized windrows were compared. It is obvious, however, that striking differences in curing rate and quality may be

FIGURE 5.—Surface view of alfalfa hay in a typical windrow made by a side-delivery rake. In comparative studies the type of rake did not materially influence either the percentage of leaves exposed at the surface or the rate of moisture loss from the forage

expected when the small windrows commonly made with the side-delivery rake are compared with the large windrows usually made by the sulky rake in farm practice. Examination of the forage in the windrows disclosed no material differences with respect to the percentage of exposed leaves in relation to rake type. (Fig. 5.)

TIME OF CUTTING DURING DAY IN RELATION TO CURING

Special cuttings of hay were made at 1 and 5 p. m. during each test for comparison with the hay cut at 9 a. m. as to quality and time required for curing. All hay in this comparison was raked into medium-sized windrows with a side-delivery rake. The hay cut at 1 p. m. was raked at 5 p. m. and that cut at 5 p. m. at 9 o'clock the following morning.

TABLE 8.—*Effect of cutting at various times during the day upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of cutting and raking	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Hay cut at 9 a. m.:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Raked immediately	82	22	2.3	53	40	17.4	2 L
Raked after 4 hours	60	24	2.2	61	40	17.1	1
Raked after 8 hours	54	25	2.0	59	41	17.4	2 L
Hay cut at 1 p. m., raked after 4 hours	59	25	2.0	67	43	17.2	1
Hay cut at 5 p. m., raked after 16 hours	54	26	2.2	63	42	17.1	1

[1] For explanation of quality factors see Table 2, footnote 2.

These results together with those for hay cut at 9 a. m. and raked immediately, and four and eight hours after cutting are shown in Table 8. In an average of the six duplicate tests, there was no marked difference with respect to quality and time required for curing except that the hay raked immediately after cutting required 22 to 28 hours longer for curing and was materially reduced in color.

RELATION OF COCK CURING TO HAY QUALITY

In order to study the effect of cock curing on hay quality and the time required for curing, hay was raked in medium-sized windrows and cocked immediately after cutting, and 4, 8, and 24 hours after cutting. Small and large cocks (eight or four cocks per plot) were made in all cases. In addition, small cocks were made following four hours of windrow curing where hay had been raked immediately, and four hours after cutting. For comparison the average results for windrowed hay (Table 4) are also included. The data are reported in Table 9.

TABLE 9.—*Effect of immediate and delayed raking and cocking upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of raking and cocking and size of cock	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Medium windrow	80	22	2.2	53	40	17.4	2 L
Cocked at once—							
Small cock	185	24	2.2	46	40	17.0	2 L–S[2]
Large cock	246	22	2.0	38	41	17.2	2 L–S[2]
Cocked after 4 hours [2]—							
Small cock	182	20	2.0	50	41	17.2	2 L–S[2]
Raked 4 hours after cutting:							
Medium windrow	60	24	2.2	61	41	17.2	1
Cocked at once—							
Small cock	177	19	2.2	54	40	17.6	2 L–S[2]
Large cock	224	21	2.0	51	42	17.3	2 L–S[1]
Cocked after 4 hours [2]—							
Small cock	177	19	2.2	53	41	17.6	2 L–S[2]
Raked 8 hours after cutting:							
Medium windrow	52	26	2.0	60	42	17.4	1
Cocked at once—							
Small cock	145	21	2.2	58	42	17.4	2 L–S[2]
Large cock	172	23	2.0	53	41	17.5	2 L–S[2]
Raked 24 hours after cutting:							
Medium windrow	52	26	2.1	61	41	17.3	1
Cocked at once—							
Small cock	150	20	2.2	54	42	17.5	2 L–S[1]
Large cock	160	24	2.0	52	40	17.1	2 L–S[2]

[1] For explanation of quality factors see Table 2, footnote 2.
[2] Results for the 2 types of rakes are averaged.

As an average of the six tests, the cocked hay required from two and one-half to three times as long to become field cured as comparable hay cured in medium-sized windrows. The color of the cocked hay ranged from 38 to 58 per cent, compared with 53 and 61 per cent for windrowed hay. The latter averaged grade 1 except that which was raked immediately after cutting, which fell into grade 2 because of too low color. On the other hand, all cocked hay (as an average) fell into grade 2 because of color, and into Sample grade 25 times out of 60 because of a moldy or musty condition. Every method of cock curing resulted in one or more moldy samples during the six tests. Differences in leafiness were not significant, and in all cases they averaged sufficiently high for grade 1 hay.

The cock-cured hay as a whole was better than the windrowed hay in 1 test out of 6. In a total of 60 comparisons between windrowed and cocked hay, the latter graded higher than windrowed hay 13 times and lower 31 times.

EFFECT OF TURNING HAY EXPOSED TO EXTERNAL MOISTURE

A number of comparisons were made in the tests beginning June 18 and August 14 wherein a portion of the hay on a number of plots was turned or scattered following exposure to rain. As an average of 33 comparisons, including both windrows and cocks (Table 10), the hay

TABLE 10.—*Effect of turning and scattering partially cured windrowed and cocked hay, after exposure to external moisture, upon its quality and the time required for drying*

Treatment	Number of plots averaged	Field-cured hay					
		Hours required	Moisture content	Quality[1]			
				Color	Leaves	Protein	Grade
Tests beginning June 18:							
Windrows—			*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Turned	15	167	19	40	34	16.5	2
Not turned	15	186	20	39	33	16.3	2
Cocks—							
Scattered	4	192	19	40	34	16.5	2–S[1]
Not scattered	4	300	25	41	36	16.7	2–S[2]
Tests beginning August 14:							
Windrows—							
Turned	2	131	15	43	38	17.0	2–S[2]
Not turned	2	131	15	40	38	16.9	2–S[2]
Cocks—							
Scattered	12	142	13	44	36	16.2	2–S[5]
Not scattered	12	159	19	53	38	16.5	2–S[9]
Averages:							
Windrows and cocks—							
Turned	33	159	16	42	35	16.4	2–S[9]
Not turned	33	187	20	43	36	16.5	2–S[13]

[1] For explanation of quality factors see Table 2, footnote 2.

that was turned or scattered became dry in 159 hours after cutting, compared with 187 hours for hay that was not disturbed. There were 9 and 13 Sample grades, due to a moldy or musty condition, among the turned and unturned hay, respectively. Differences in color, leaf composition, and protein content did not appear significant.

EFFECT OF RAIN ON PROTEIN CONTENT

It seemed of interest to determine what effect exposure to rain might have on the quality of alfalfa hay aside from actual leaf loss. It was possible to select 21 lots of hay from the tests beginning June 18, July 11, and August 14 which had not been exposed to much rain and an equal number of samples of practically the same leaf content but which had been exposed to more than 1 inch of rain. The results as averaged in Table 11 show that the hay that had been rained on, although exposed much longer in the field with a resulting lower color value, had slightly more protein than hay not exposed to rain.

TABLE 11.—*Comparative quality of alfalfa hay that has been exposed to rain and equally leafy hay not so exposed*

Number of comparisons	Exposed to rain	Field-cured hay					
		Hours required	Moisture content	Quality [1]			
				Color	Leaves	Protein	Grade
			Per cent	*Per cent*	*Per cent*	*Per cent*	
Tests beginning June 18:							
14	No	74	28	48	36.8	16.9	2
14	Yes	191	23	40	36.4	17.0	2
Tests beginning July 11:							
5	No	54	31	57	39.2	17.9	2
5	Yes	136	31	32	39.2	18.6	3
Tests beginning August 14:							
2	No	44.	17	65	38.0	16.4	1
2	Yes	131	15	40	38.0	16.8	S[2]
Averages:							
21	No	57	25	57	38.0	17.1	2
21	Yes	153	23	37	37.9	17.5	2–S[2]

[1] For explanation of quality factors see Table 2, footnote 2.

EFFECT OF ARTIFICIAL DRYING

In conjunction with these field-curing studies, the Bureau of Public Roads of the United States Department of Agriculture cooperated in determining the effect of artificial drying upon the quality of alfalfa hay. These results as published elsewhere (Hurst and Kiesselbach (*4*)) are summarized in Table 12 to contrast rapid drying with field curing and prolonged drying.

As an average of 12 lots of hay which were dried with heated air, it required 2¾ hours to reduce the hay to 21 per cent moisture. This hay graded No. 1, extra leafy, averaged 20.4 per cent protein, retained 67 per cent of its color, and had pliable stems.

TABLE 12.—*Effect of the rapidity of drying upon the quality of alfalfa hay*

Mode of drying	Number of samples	Cured hay							
		Hours required	Moisture content	Quality [1]					
				Stems	Color	Leaves	Protein	Grade	
			Per cent		*Per cent*	*Per cent*	*Per cent*		
Artificially dried	12	2¾	21	1	67	52	20.4	1 Exl.	
Field cured	8	41	25	1.5	60	48	19.5	1	
Cured indoors	1	127	----------	1	65	52	20.9	1 Exl.	

[1] For explanation of quality factors see Table 2, footnote 2.

In contrast, eight comparable samples which were cured in the field required 41 hours to reach a moisture content of 25 per cent. This hay averaged grade No. 1, 19.5 per cent protein, 60 per cent color, and medium hard stems.

One sample which was cured indoors required 127 hours for drying, graded No. 1 extra leafy, 20.9 per cent protein, 65 per cent color, and had pliable stems.

The field-cured hay and the sample that was cured indoors were cut on July 23. The field-cured hay remained four hours in the swath prior to being raked into medium-sized windrows where curing was finished. The artificially dried hay was cut from adjacent plots during the period of July 24 and 28 and was removed immediately to the drying equipment.

These data suggest that the three methods of curing produced hay of almost identical quality. The slightly lower leaf and protein content of the field-cured hay was doubtless due to mechanical loss of leaves, since it is safe to assume that even the best method of field curing is likely to result in some loss of leaves.

Quantities of the artificially dried and of the field-cured hay from the above experiment were supplied to the poultry husbandry department of the Nebraska Agricultural Experiment Station for comparison in feeding to young chickens. The leaves from both lots of hay were fed to two groups of 35 chicks each in connection with a basal ration low in vitamin A. Differences in growth due to feeding the alfalfa cured under these two extreme conditions were not significant.

RELATION OF LEAFINESS OF CURED HAY TO PROTEIN CONTENT

It is generally considered that approximately three-fourths of the protein of alfalfa is contained in its leaves. This estimate is in close agreement with the average of determinations made in connection with the six main tests herein reported. At the time of cutting, composite samples were taken and analyzed for leafiness and for protein content of the leaves and stems separately. (Table 2.) The leaves were found to constitute 47 per cent of the dry weight. These analyzed 27.5 per cent protein, while the stems contained 11.4 per cent. According to these figures, 68 per cent of the total protein was contained in the leaves. These results correspond with those previously reported by the writers (*4*), in which, as a 4-year average, the portion of the protein borne by the leaves ranged from 75 per cent in the prebloom stage to 70 per cent in the full-bloom stage.

Since more or less shattering of leaves occurs with the various haymaking operations, the question arises as to just what may be the relation between the leafiness and the protein percentage of alfalfa hay. In answer to this question, the coefficients of correlation between the proportion of leaves by weight and the protein percentage of the hay have been calculated for the various samples of these six main curing tests. The number of samples available for any one test ranged from 40 to 46. The respective coefficients of correlation for these six tests were 0.933 ± 0.021, 0.572 ± 0.106, 0.899 ± 0.029, 0.861 ± 0.038, 0.826 ± 0.048, and 0.922 ± 0.024. A combined correlation coefficient for the six tests was 0.864 ± 0.011 *(3a, p. 163)*. The correlation for the entire 253 samples considered collectively was 0.721 ± 0.026. The distribution of the 253 samples with respect to leafiness and protein is shown in Table 13.

TABLE 13.—*Distribution of 253 samples of alfalfa hay with respect to leafiness and protein content, 1928*

Percentage of leaves	Number of samples having a percentage protein content of—																	Frequency
	13.2	13.7	14.2	14.7	15.2	15.7	16.2	16.7	17.2	17.7	18.2	18.7	19.2	19.7	20.2	20.7	21.2	
20		1																1
21																		
22	1																	1
23																		
24																		
25																		
26		1																1
27				1														1
28																		
29		1																1
30				1														1
31							1											1
32					1													1
33						3	3		1									7
34							2	1	1	1								5
35					1	1	1	3	1									7
36					2	3	5	5	1	1								17
37					1		8	5	2									16
38						1	7	5	4	2	3	2						24
39						1	2	8		2	1							14
40						3	4	7	2	1	1							18
41						1	3	6	4	2	6							22
42							4	4		2	5	5	1					21
43								10	4	1	2	1	2					20
44								6	1		2	6		5				20
45								1	5	2			1					9
46								3	1	2		3	1	1				11
47								1	3	5	1	1	2	1				14
48											1			2				3
49									1	2	1	1		2				7
50												1		2	1		1	5
51												1				1		2
52															1	1		2
53													1					1
Frequency	1	3		2	5	13	40	65	31	23	23	21	8	13	2	2	1	253

PROGRESSIVE LOSS OF WATER FROM ALFALFA IN RELATION TO CURING PRACTICE

The comparative rates of water loss from alfalfa curing in the swath and under various methods of raking and cocking were determined for the first three days of four of the foregoing tests. These methods included raking the hay with side-delivery and sulky rakes into small, medium, and large windrows immediately and four hours after cutting. An additional medium-sized windrow included in each case was turned after four hours of windrow curing. Comparative cock curing was also determined in the case of small and large cocks when cocked immediately and after four hours of swath curing. The rate of drying was established by determining the moisture content of composite samples of hay taken from each condition at 9 a.m., and 1 and 5 p.m. The results are reported in Table 14.

As a grand average, the hay in the swath cured more rapidly than the hay cured under any of the other conditions. Swath-cured hay reached a field-cured condition during the second afternoon, compared with the third afternoon for the hay curing under most of the other practices. The large windrows raked immediately after cutting and all of the cocked hay still remained uncured at the close of the third day. Curing was rather consistently retarded as the

size of windrow or cock was increased. Turning the windrow after four hours of windrow curing slightly increased the curing rate. Hay curing in the swath or small windrows was more affected by external moisture, such as higher humidity and dews, than was the hay in the larger windrows and cocks. Comparative differences due to the various practices were less marked when partial swath curing preceded windrowing.

TABLE 14.—*Comparative rates of curing alfalfa hay in the swath and under various methods of raking and cocking, the hay being cut at 9 a. m.*

[Average of four tests]

Time and methods of raking and cocking	Moisture content of hay (per cent)								
	First day			Second day			Third day		
	9 a. m.	1 p. m.	5 p. m.	9 a. m.	1 p. m.	5 p. m.	9 a. m.	1 p. m.	5 p. m.
Cured in the swath	75.3	57.3	42.5	46.5	28.8	23.8	31.8	19.8	19.3
Raked immediately:									
Side-delivery rake—									
Small windrow		63.0	53.8	49.3	37.5	32.3	39.5	27.5	21.5
Medium windrow		66.8	59.0	53.8	42.0	34.5	43.8	27.8	21.8
Medium windrow [1]		63.0	53.3	50.0	39.3	33.5	35.5	32.7	20.8
Large windrow		66.5	56.5	56.8	47.0	38.3	41.8	37.3	27.3
Average		64.8	55.7	52.5	41.5	34.7	40.2	31.3	22.9
Sulky rake—									
Small windrow		62.8	49.8	42.0	32.3	27.0	35.3	24.3	22.0
Medium windrow		61.8	50.0	50.8	38.3	32.0	35.3	24.8	22.5
Medium windrow [1]		60.8	53.3	48.5	36.5	30.5	33.8	23.3	22.8
Large windrow		62.3	52.8	55.5	42.0	39.0	45.0	31.5	27.7
Average		61.9	51.5	49.2	37.3	32.1	37.4	26.0	23.8
Raked at 1 p. m.:									
Side-delivery rake—									
Small windrow			47.3	45.3	30.8	26.3	33.0	23.0	20.8
Medium windrow			45.8	43.3	34.0	32.5	35.0	23.8	22.3
Medium windrow [1]			47.0	42.0	33.3	26.3	32.3	23.0	21.5
Large windrow			49.8	44.8	37.8	35.0	34.1	26.0	22.5
Average			47.5	43.9	34.0	30.0	33.6	24.0	21.8
Sulky rake—									
Small windrow			48.0	43.8	32.8	27.8	33.5	22.5	17.8
Medium windrow			44.8	42.0	31.3	30.3	31.3	22.3	22.3
Medium windrow [1]			43.5	43.5	31.8	28.5	30.0	23.0	21.3
Large windrow			45.3	41.0	34.5	29.3	33.8	25.8	25.8
Average			45.4	42.6	32.6	29.0	32.2	23.4	21.8
Raked and cocked immediately:									
Small cock		66.8	61.8	61.3	59.8	54.0	51.8	47.5	41.0
Large cock		67.5	64.5	64.0	60.5	59.0	55.8	53.8	51.8
Raked and cocked at 1 p. m.:									
Small cock			47.5	45.8	40.3	37.0	38.0	34.3	32.8
Large cock			52.3	45.8	40.3	38.8	40.3	35.0	31.5
Grand average									
Cured in the swath	75.3	57.3	42.5	46.5	28.8	23.8	31.8	19.8	19.3
Raked immediately:									
Small windrow		62.9	51.8	45.7	34.9	29.7	37.4	25.9	21.8
Medium windrow		64.3	54.5	52.3	40.2	33.3	39.6	26.3	22.2
Medium windrow [1]		61.9	53.3	49.3	37.9	32.0	34.7	28.0	21.8
Large windrow		64.4	54.7	56.2	44.5	38.7	43.4	34.4	27.5
Average		63.4	53.6	50.9	39.4	33.4	38.8	28.7	23.3
Cock (average)		67.2	63.2	62.7	60.2	56.5	53.8	50.7	46.4
Raked at 1 p. m.:									
Small windrow			47.7	44.6	31.8	27.1	33.3	22.8	19.3
Medium windrow			45.3	42.7	32.7	31.4	33.2	23.1	22.3
Medium windrow [1]			45.3	42.8	32.6	27.4	31.2	23.0	21.4
Large windrow			47.6	42.9	36.2	32.2	34.0	25.9	24.2
Average			46.5	43.3	33.3	29.5	32.9	23.7	21.8
Cock (average)			49.9	45.8	40.3	37.9	39.2	34.7	32.2

[1] Hay turned after four hours of windrow curing.

Although it was not altogether consistent, there was a slight indication that the hay in the windrows raked by the sulky rake cured more rapidly than that raked by the side-delivery rake. This difference in curing rate may have been due to a somewhat greater surface exposure of the windrows made by the sulky rake.

HOW MOISTURE IS LOST FROM STEMS IN CURING

In view of conflicting opinion, it seemed desirable to study further the loss of moisture from cut alfalfa stems. Previous studies by Willard (*13*), Westover (*12*), and Kiesselbach and Anderson (*5*, *6*) have shown that the leaves do not function materially in withdrawing moisture from the stems during the curing period. It has not been shown, however, to what extent moisture loss may take place through "bleeding" or direct evaporation from the cut ends of the stems.

During each of two tests three small samples of freshly cut alfalfa were prepared in duplicate for curing in the laboratory, as follows: (1) Normal stems as cut in the field, (2) normal stems with the cut end sealed with waterproof wax, (3) stems with leaves removed and all mutilated stem and branch ends sealed with wax.

The hay was taken to the laboratory, the various samples prepared, and first weights taken within 30 minutes after cutting. The samples were scattered thinly on paper (the detached leaves with the stems) in a well-ventilated room for drying. Weights were taken at hourly intervals during the first day and three times each during the second and third days. The comparative rates of accumulative moisture loss under the various treatments are shown in Table 15.

BLEEDING FROM STEM ENDS OF CUT ALFALFA

A study of the data reveals no material acceleration of moisture loss through bleeding in the case of normal alfalfa cut as for hay. The water losses for the entire period averaged but 0.3 per cent greater for the unsealed than for the sealed stems. This suggests that the loss of water from alfalfa during the curing process is primarily by direct evaporation through the epidermis of the stems and leaves and not by exit through the cut ends of the stems.

TABLE 15.—*Progressive rates of moisture loss from cut alfalfa plants, under laboratory conditions, when all points of mutilation on the stems are sealed, as compared with unsealed stems*

Period	Treatment of—		Initial water content	Accumulative percentage of the initial moisture content that is lost during drying																	
				First day											Second day			Third day		
	Leaves	Stems		8 a. m.	9 a. m.	10 a.m.	11 a.m.	12 m.	1 p. m.	2 p. m.	3 p. m.	4 p. m.	5 p. m.	6 p. m.	7 a. m.	1 p. m.	6 p. m.	7 a. m.	1 p. m.	6 p. m.
			Per ct.																	
Sept. 6 to 8	Attached	Unsealed	76.4	0	7.5	12.0	16.5	19.3	23.8	28.0	32.1	35.5	39.1	41.2	64.6	73.2	80.5	86.3	87.8	89.8
	do	Sealed	75.3	0	7.6	11.6	16.2	19.0	23.0	27.5	31.4	35.2	38.6	40.9	63.3	72.9	80.1	86.1	87.5	90.3
	Detached	do	75.1	0	3.0	10.5	11.9	15.1	19.6	24.3	28.7	31.9	36.3	38.5	60.6	69.2	76.0	82.8	84.0	87.4
Sept. 13 to 15	Attached	Unsealed	75.9	0	7.4	13.2	17.4	22.1	26.9	32.1	37.6	42.9	47.0	51.1	76.7	82.5	85.8	88.9	90.0	92.3
	do	Sealed	75.4	0	7.2	12.5	17.1	22.0	26.8	32.0	37.6	43.0	47.3	51.0	77.0	82.3	85.9	88.7	89.9	92.1
	Detached	do	75.8	0	6.0	11.0	15.9	20.9	26.3	31.5	37.1	42.1	46.4	50.1	73.1	79.6	83.1	86.5	87.7	90.4
Average	Attached	Unsealed	76.2	0	7.5	12.6	17.0	20.7	25.4	30.1	34.9	39.2	43.1	46.2	70.7	77.9	83.2	87.6	88.9	91.1
	do	Sealed	75.4	0	7.4	12.1	16.7	20.5	24.9	29.8	34.5	39.1	43.0	46.0	70.2	77.6	83.0	87.4	88.7	91.2
	Detached	do	75.5	0	4.5	10.8	13.9	18.0	23.0	27.9	32.9	37.0	41.4	44.3	66.9	74.4	79.6	84.7	85.9	88.9

A direct comparison may be made of the rate of water loss from the alfalfa having its leaves intact with that from alfalfa having the leaves removed and all cut ends of the branches sealed. Since bleeding was prevented, any pumping action of the leaves in drying out the stems should be reflected in a differential rate of water loss from the two kinds of samples. As an average for the 16 successive readings, the rate of water loss was retarded 3 per cent by removing the leaves. This slight difference is not regarded as significant, since it may have been due in part to an unavoidable waxing of the stem epidermis in close proximity to the cut surface at the time of applying the wax.

All of these data suggest that both bleeding from the stem ends and the transpiratory function of the leaves are negligible factors under field-curing conditions.

DISCUSSION AND CONCLUSIONS

In view of the fact that nearly three-fourths of the protein of alfalfa is found in the leaves, any practical plan for curing the hay will be directed toward leaf conservation. The loss from leaf shattering is twofold. It results in an actual reduction in the yield and also in the quality of the hay. In these tests the leaves constituted 47 per cent of the entire crop, and analysis showed their protein content to be 141 per cent higher than that of the stems. The self-evident relation of leafiness to protein content and feeding value is borne out by the high average correlation coefficient of 0.864 ± 0.011 between the two factors—leafiness and protein content. Another important consideration is the avoidance of unnecessary damage due to rain. This is best accomplished through the use of methods that hasten the evaporation of moisture from the alfalfa and thereby shorten the interval between cutting and storage. So long as the forage remains in the swath, windrow, or cock, it is subject to spoilage due to rain. This often leads to serious discoloration and mustiness, as well as added loss of leaves. The trade regards the presence of mold or must so unfavorably that hay so affected is immediately designated as Sample grade.

Conclusions may be drawn from the average of six duplicate curing tests regarding the degree to which various practices succeed in meeting these specified requirements. It appears that there may be considerable latitude in procedure and yet that adherence to certain cardinal principles leads to best results.

The question often arises as to what is the best time of day to cut alfalfa with respect to likelihood of favorable curing. No marked difference was experienced in the time required or in the quality of hay, whether the cutting was done in the morning, at midday, or in the late afternoon, provided comparable swath curing preceded raking. Naturally, cutting should be delayed until the dew has dried from the plants. Whatever the time of cutting, the raking should be done before the leaves dry sufficiently to cause much shattering. No specified time limit can be set for the duration of this initial curing in the swath because of variability in both weather and condition of the hay. Ordinarily a period of about four to eight hours in the swath prior to windrowing will materially facilitate rapid drying

in case the hay is cut in the forenoon or early afternoon. Favorable results may be expected by cutting in late afternoon and delaying the raking until after the dew has dried off the following forenoon. Very little discoloration will result from a heavy dew or light rain while the cut alfalfa is still in a fairly fresh or unwilted condition. In these tests, raking the hay immediately following the mower has lengthened the curing period and lowered the color regardless of the type of rake or the size of windrow.

If for any reason alfalfa hay has been permitted to overcure in the swath so that handling in this dry condition may result in serious loss of leaves, such leaf shattering may be materially lowered by raking early in the morning while the hay is tough from dew. The leafiness of overcured hay was 6 per cent greater when raking was done in the morning while the hay was damp than when raking was delayed until midday.

As might be expected, increase in size of windrow resulted in reduced curing rate. It may be assumed that the larger the mass the slower the evaporation. This is especially pronounced in the case of immediate raking. In averaging six tests, small, medium, and large windrows containing 2, 4, and 8 mower swaths, respectively, the hay required 64, 80, and 92 hours to reach a fairly comparable cured condition when raked immediately after cutting. When four hours' swath curing preceded raking, the hay in corresponding windrow sizes required 50, 60, and 71 hours, respectively.

The direction of raking with either type of rake, whether parallel or crosswise to the mower swath, had no material effect upon either the rate of curing or the quality of the hay. The same may be said with respect to the direction of the windrow.

From the data at hand it appears to make no difference in the quality or curing rate of the hay whether it is windrowed with a side-delivery or a sulky rake, provided comparable conditions are maintained. Of course, if the customary small windrow made by the side-delivery rake is contrasted with the usual large windrow of the sulky rake, it is to be expected that the former will cure more rapidly. When comparable windrows of equal size were compared, the sulky rake was fully as effective with respect to drying rate. In the case of immediate raking, small windrows made by a side-delivery rake required 64 hours and large windrows made by a sulky rake 90 hours to reach a cured condition. Reversing the comparison, small windrows made by a sulky rake cured in 63 hours and large windrows made by a side-delivery rake in 94 hours. A continuation of the normal functioning of transpiration by the leaves in withdrawing moisture from the cut stems within the windrows appears equally unimportant with windrows made by either type of rake. Evidently choice of rake type may be based upon questions pertaining to their comparative efficiency of operation.

Under normal conditions the time required for curing may be somewhat shortened by turning the windrows. Such treatment after 4 hours of windrow curing shortened the curing period 16 hours when the hay was raked immediately after cutting and 4 hours when it was raked 4 hours after cutting. No change in commercial grade resulted from such turning, although the color was somewhat improved in the case of hay raked immediately after cutting.

Under some circumstances, as in the case of rain or very slow drying weather, it may prove desirable to turn the windrows. The side-delivery rake is superior for this purpose.

Ordinarily under such conditions as prevail in Nebraska, cocking alfalfa hay as a part of the curing procedure is inadvisable. Such practice, regardless of the size of cocks, retards moisture loss and exposes the hay in the field to greater chances of damage from rain. In these experiments the time required was increased nearly threefold as compared with combined swath and windrow curing. Cocking did not appreciably improve the color, leafiness, protein, or other properties of the hay. On the other hand, because of rain and slow drying, it frequently resulted in musty or moldy forage which of necessity was placed in Sample grade.

Under continued favorable drying conditions, a maximum of color and leafiness is retained by the hay placed in relatively large windrows or cocks as soon as it has reached a wilted condition. Loss of color through bleaching is then largely in proportion to the amount of surface exposure.

Turning or scattering partially cured windrows or cocks that have become wet from rain has shortened the period of curing 28 hours as an average for 33 trials. Such turning had practically no effect upon the color, leafiness, or protein content. However, more cases of Sample grade, due to mustiness, developed where the hay was not turned.

Hay dried in 2¾ hours with heated air by means of a forced draft did not differ materially in quality from hay requiring 127 hours for curing indoors, and it was but slightly higher in color, leaves, and protein than hay cured in the field by a favorable combination of swath and windrow curing. In a poultry-feeding comparison by the poultry department of the Nebraska station, in which artificially dried and field-cured alfalfa samples from these experiments were included in a basic ration which was lacking in vitamin A, no significant differences resulted.

Regardless of the curing practice, all hay of good quality produced in these experiments was characterized by a sweet fragrant odor. In no case, however, was a distinct aroma observed.

Considerable interest has attached to the question of how the moisture is removed from the stems of cut alfalfa during the curing process. Investigations of this problem have indicated that neither bleeding from the cut end nor transpiration by a continuation of normal leaf functioning are appreciable factors. The internal moisture appears to make its exit by direct evaporation through the stem epidermis, which is well supplied with stomatal apertures.

LITERATURE CITED

(1) Cox, J. F.
1927. REPORT OF THE SECTION OF FARM CROPS. Mich. Agr. Expt. Sta. Ann. Rpt. 39: 356–357.
(2) —— and Megee, C. R.
1928. ALFALFA. 101 p., illus. New York and London.
(3) Curtiss, C. F.
1928. BOTANY AND PLANT PATHOLOGY. Iowa Agr. Expt. Sta. Ann. Rpt. 1928: 27–29.
(3a) Fisher, R. A.
1928. STATISTICAL METHODS FOR RESEARCH WORKERS. Ed. 2, rev. and enl., 269 p., illus. Edinburgh and London.
(4) Hurst, W. M., and Kiesselbach, T. A.
1929. DRYING ALFALFA HAY BY FORCED DRAFT WITH HEATED AIR. Agr. Engin. 10: 218–220.
(5) Kiesselbach, T. A., and Anderson, A.
1926. ALFALFA INVESTIGATIONS. Nebr. Agr. Expt. Sta. Research Bul. 36, 125 p., illus.
(6) ——— and Anderson, A.
1927. CURING ALFALFA HAY. Jour. Amer. Soc. Agron. 19: 116–126, illus.
(7) Mason, A. J.
1926. PROFITS OF A "PROTEIN FARM." Farm Jour. 50 (2): 13, 96, illus.
(8) Parker, E. C.
1929. HIGH-GRADE ALFALFA HAY: METHODS OF PRODUCING, BALING, AND LOADING FOR MARKET. U. S. Dept. Agr. Farmers' Bul. 1539, 26 p., illus.
(9) Russell, H. L.
1927. VITAMINS DISCOVERED BY CHEMISTS HAVE WIDE FARM APPLICATIONS. Wis. Agr. Expt. Sta. Bul. 396 (Ann. Rpt. 44): [40]–44, illus.
(10) Russell, W. C.
1929. THE EFFECT OF THE CURING PROCESS UPON THE VITAMIN A AND D CONTENT OF ALFALFA. Jour. Biol. Chem. 85: 289–297.
(11) Steenbock, H., Hart, E. B., Elvehjem, C. A., and Kletzien, S. W. F.
1925. DIETARY FACTORS INFLUENCING CALCIUM ASSIMILATION. VI. THE ANTIRACHITIC PROPERTIES OF HAYS AS RELATED TO CLIMATIC CONDITIONS WITH SOME OBSERVATIONS ON THE EFFECT OF IRRADIATION WITH ULTRA-VIOLET LIGHT. Jour. Biol. Chem. 66: 425–440, illus.
(12) Westover, H. L.
1926. COMPARATIVE SHRINKAGE IN WEIGHT OF ALFALFA CURED WITH LEAVES ATTACHED AND REMOVED. U. S. Dept. Agr. Bul. 1424, 11 p.
(13) Willard, G. J.
1926. DO LEGUME LEAVES HASTEN THE CURING PROCESS BY PUMPING MOISTURE FROM THE STEMS? Jour. Amer. Soc. Agron. 18: 369–375.

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26

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THE TIME TO HARVEST FIBER FLAX[1]

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CONTENTS

	Page		Page
Introduction	1	Yield of fiber	15
Review of literature	2	Quality of fiber	16
Experimental methods	4	Discussion	18
Yield of seed	8	Summary	21
Germination of seed	10	Literature cited	21
Yield of straw	15		

INTRODUCTION

Fiber flax is harvested at various stages, depending upon the climate in which it is grown and the purpose for which the flax is intended. It has generally been thought that fiber flax should be harvested early for fiber of the best quality and later for good seed. It has been said that the best fiber can not be obtained if good seed is produced and vice versa. Therefore the time to harvest may be considered a very important agronomic point in the yield and quality of the straw, fiber, and seed. In some localities the farmer can harvest at only one stage, due to climatic conditions which would prevent earlier or later pulling. In other sections the harvest, if desired, could be accomplished over a longer period of time; hence the maturity of the plant might be a determining factor in deciding when to begin to harvest.

The harvest stages of flax are called green ripe, yellow ripe, and full ripe. In the United States fiber flax may be harvested at all three stages, but it is rarely pulled at the green-ripe stage. This is, however, the common stage for pulling in Ireland and to some extent in western continental Europe, where the best quality of fiber is produced. Green ripe refers to the plant at an early stage after full bloom, when the stems and leaves are green. During this period the fiber separates easily and yields a very fine product, but the seed is entirely sacrificed. Yellow ripe refers to a later stage of develop-

[1] The experiments reported were carried on in cooperation with the Michigan Agricultural Experiment Station.

[2] The writer expresses his appreciation for assistance given and suggestions made by Lyster H. Dewey, senior botanist in charge, Office of Fiber Plants, Bureau of Plant Industry, and for the help of B. E. Hartsuch, chemistry department, Michigan State College, in performing the chemical work and making suggestions.

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ment when the stems and leaves have turned yellow because of loss of chlorophyll and many of the leaves have fallen off. Plants harvested at this stage have a medium-fine fiber which is stronger than that harvested at the earlier period. In the late yellow-ripe stage the seed is also obtained, which is an important source of revenue. Full ripe is what the name implies; the seed is fully developed and the plant is mature or dead. The fiber at this stage is said to be lignified and is difficult to separate from the wood. It has lost its silkiness, luster, and elasticity and has become of secondary importance to the seed. The seed is of very good quality, but little, if at all, better than that obtained in the late yellow-ripe stage. If the weather at harvest time is very wet, the plants will remain green, although the seed may be fully developed. This occurs sometimes in Michigan, but rarely in Oregon where fiber flax is grown. The dry harvest season in Oregon cures the flax to a beautiful yellow color, and there the bolls remain yellow even at the full maturity stage.

In the United States and Canada very little fiber flax has been pulled during the green stage in recent years because the maximum yield of seed has usually been desired, and the farmers have waited for a late yellow-ripe or full-ripe stage. Nearly all the American fiber-flax farmers pull their flax in the late yellow-ripe stage.

In selecting the time to harvest fiber flax in the United States and Canada, most farmers follow the rule of harvesting when one-third to one-half of the seed bolls are yellow to brown with fully developed brownish seeds. At this time the stems have usually turned yellow and the leaves have fallen off the stem two-thirds of the distance up from the ground. Experience shows that if flax is cut or pulled at this time immature seed will mature in the shock and the yield of seed will be as large as if harvested later. Further, the fiber will be of good quality under average climatic conditions, and this is considered the most profitable period for harvesting fiber flax under our economic system. If there is rainy weather at harvest time, flax is likely to make a "second growth," and this does not allow one to judge the stage of the plant very well by the color of the stem. The stem will remain green and the leaves that ordinarily fall off will remain or new leaves will be produced. In cases of this kind it is necessary to judge the maturity of the plant by the seed bolls. The seeds in the bolls rattle when they are hard and mature, and the harvest begins as soon as this becomes noticeable. Fiber-flax fields may have a red appearance when dead ripe, and it is desirable to pull before this stage is reached.

REVIEW OF LITERATURE

There has been little scientific investigation covering completely the time to harvest fiber flax. Tobler (*18*)[3] in the most recent scientific book on fiber-flax culture cites the more important research publications on this subject. Ivanow (*14*) made a number of chemical analyses of the vegetative parts of the plant (leaves, stems, and roots together) and also of the seed. These analyses, made at four different stages in the growth, showed an increase of the oil in the seed as it matured. A small decrease occurred in the percentage of ether extract and in the iodine number of the vegetative parts of the plant from

[3] Italic numbers in parentheses refer to Literature Cited, p. 21.

the seedling stage to the formation of flower buds. No data were given for the vegetative parts after flowering started. Starch and sugars also were studied by Ivanow, as he attempted to show the source of food used in the oil formation of the seed. Dillman (*9*) has made recent studies upon the oil content of the maturing seed of flax, and his results show a steady and rapid increase in the formation of oil in dry seeds from 7 days after flowering until 25 days after flowering, when a constant is reached. His work was conducted upon a seed-flax variety and does not give results directly applicable for fiber flax because in the field the flowers do not all blossom at the same time but over a period of several days, and information is desired regarding the oil content of immature and mature seed together as it is produced, pulled, and cured in the green and yellow stages.

Hutchinson (*13*) conducted the most extensive tests upon the production and quality of fiber harvested at different stages. His results showed that in general the latest date of harvesting gives the greatest yields of fiber and seed, but in certain tests the opposite results were secured. His results were based upon the averages of three plots for each stage, pullings being made once a week for four weeks. In certain years the delayed harvest resulted in more and stronger fiber, but there was little difference in the quality except in strength. He stated (*12*) that silkiness or oiliness is essential to spinning, as a dry, bare fiber yields a product of lower value.

Barker (*3*), Barker and Eyre (*4*), Eyre and Fisher (*10*) have brought forward evidence to discredit the view that ripening seed on the flax plant drains from the stem an oleaginous sap, thereby impairing the quality of the fiber resulting from such straw. They show that when flax is grown as a fiber crop and has come to the proper state for pulling, which is reached about three weeks after full flowering, the oil content of the seed has reached its maximum and the seed is developed sufficiently for use as a sowing seed.

It is thought by some that the amount of oil present in the flax fiber is an indication of quality. Fargher and Withers (*11*), writing about cotton, state:

> It is generally agreed that at the customary temperature of the spinning mill the waxes in the fiber become soft and semiliquid, and thus allow the proper working of the cotton. After spinning, the oil sets and cements the fibers. Spinning trials of Egyptian cotton deprived of its wax showed that the material behaves very badly in the drawing and spinning processes, giving an excessive amount of waste, irregular results, and showing a tendency to adhere to the rollers.

It has been stated by Anderson (*1*), Ruschmann (*17*), and others that the harsh fiber customarily obtained in the later stages is due to the lignifying of the cellulose in the fiber cells. According to the former (*1, p. 207*):

> Lignification increases with the age of the fiber, being most widespread in the fibers at the base of the stem. It increases as the stem matures, especially in the later stages of the stem's growth, and it is this fact that plays so important a part in determining the proper time for pulling the flax plant. Flax pulled too late is regarded as "harsh"; in other words it is lignified to a greater extent than is desirable. The lignification of the middle lamella and secondary wall interferes with the easy separation of the fibers from one another and renders the commercial fiber coarser.

Ruschmann (*17, p. T64*) makes the following statement: "The fully ripe plant should never be harvested, as the divisibility and spinning quality of the flax are greatly injured by increasing lignification."

Bradbury (*5, p. 77*) states:

> It has been generally experienced that when flax straw is pulled and retted in the green state the resultant fiber is finer and silkier than the straw pulled at a later and more matured stage, but the total yield in volume and weight of fiber is relatively smaller * * *. It consequently happens that when the plants are pulled at such an early period, the seed in the bolls is immature and too small in size and too light in weight for sowing.

Bredemann (*7*) and Opitz and Pander (*15*) present data showing the effect of early harvest upon the germination of the seed and the weight of 1,000 seeds. They show significant increases in the weight of 1,000 seeds and their germination between the green-ripe and yellow-ripe, and between the yellow-ripe and full-ripe stages of maturity.

Several workers (*7, 8, 15, 19*), besides presenting results on the germination, percentage of oil, and weight per 100 seeds, have also determined the specific gravity of the seed; the iodine number, the saponification number, the refractive index, and the acid number of the oil; and the percentage of nitrogen and sucrose of seed flaxes harvested at different periods of maturity.

EXPERIMENTAL METHODS

In this bulletin are presented the results of three years' experiments upon flax plots harvested at different stages. Extensive notes were taken upon the appearance of the plants on different days in order that any harvest period might be duplicated another year. These notes are shown in Tables 1 and 2, which give the appearance of the plants on different harvest days in regard to color of the stems, presence or absence and color of the leaves, number of flowers, and size and color of the bolls and seeds from day to day.

The field from which the flax was obtained in 1926 was planted at the rate of 80 pounds of seed per acre with a force-feed, 20-disk type drill with 4 inches between the disks. The Saginaw variety of flax was used. This is a pure-line variety adapted to Michigan conditions. A strip 30 feet wide, with the drill rows running crosswise, was marked off; and on each day except Sundays, for a period of 30 days, a drill row of flax 30 feet long was pulled. Every other drill row was skipped in pulling, and 11 of these skipped rows were harvested on August 5, the last day, to check the soil heterogeneity.

TABLE 1.—*Appearance of flax plants on different days of harvest in 1926 as to color of stems, presence or absence and color of leaves, number of flowers, size and color of bolls, and condition and color of seeds*

Date of harvest	Stems		Color of leaves	Average number of flowers per plant	Bolls		Dry seeds	
	Color	Portion above root without leaves			Size	Color	Condition	Color
		Inches						
July 7	Green	8	Green	2	One-half full size	Green	Very immature and small	Greenish brown.
July 8	do	10	do	2	do	do	do	Do.
July 9	do	13	do	1	Two-thirds full size	do	Flakes	Green to greenish brown.
July 10	do	15	do	.5	do	do	do	Do.
July 12	do	17	do	.1	Three-fourths full size	do	Flat, immature, small to full size.	Do.
July 13	do	19	do	.05	do	do	do	Do.
July 14	do	20	do	.01	do	do	Immature, mostly full size, flat.	Do.
July 15	do	20	do	0	Full size	do	do	Do.
July 16	do	20	do	0	do	do	do	Mostly green, very few brown.
July 17	Turning yellow	20	Turning yellow	0	do	Turning yellow	Immature	Some gray flakes.
July 19	Yellow, 40 per cent	20	Few green	0	do	do	Maturing	Some reddish brown but mostly dark green.[1]
July 20	Yellow, 50 per cent	20	do	0	do	do	do	Do.
July 21	Yellow, 75 per cent	20	do	0	do	Yellow to brown, 75 per cent.	do	Light reddish brown, many tan, some green.
July 22	Yellow, 80 per cent	20	do	0	do	Yellow to brown, 80 per cent.	do	Do.
July 23	Yellow, 90 per cent	20	None green	0	do	do	do	Light brown, very few green.
July 24	do	20	do	0	do	do	do	Do.
July 26	do	20	Few green	0	do	Yellow to brown, 95 per cent.	do	Brown, some light colored.
July 27	Yellow	20	do	0	do	Yellow to brown	do	Do.
July 28	do	20	do	0	do	do	do	Do.
July 29	do	20	do	0	do	do	Nearly mature	Brown, no black.[2]
July 30	do	20	do	0	do	do	do	Do.
July 31	do	20	do	0	do	do	do	Do.
Aug. 2	do	20	None green	0	do	do	All mature	Dark brown, few black.
Aug. 3	Some dead	20	do	0	do	do	do	Do.
Aug. 4	Few green	20	Few green	0	do	do	do	Do.
Aug. 5	do	20	do	0	do	do	do	Do.

[1] A very marked difference in color of the seed occurred between July 20 and July 21. All seeds from plants pulled before July 20 had a greenish shade, and the seed obtained on July 21 and later had a brownish shade.

[2] A marked difference in color of the dry seeds occurred between the July and August pullings. The flax averaged 30 inches in height at maturity. The first blossoms were noticed on June 29.

TABLE 2.—*Appearance of flax plants on different days of harvest in 1927 as to color of stems, presence or absence and color of leaves, number of flowers, size and color of bolls, and condition and color of seeds* [1]

Date of harvest	Stems		Average number of flowers per plant	Bolls		Seeds			
						At harvest		After threshing (dry)	
	Color	Portion above root without leaves		Size	Color	Condition	Color	Condition	Color
		Inches							
July 5	Green [2]		2	One-third full size	Green	Watery	White	Extremely small, flat, uniform.	Dull, light brown, greenish brown.
July 7	do	8	.25	do	do	do	do	do	Do.
July 9	do	10	.13	One-half full size	do	do	do	do	Do.
July 11	do	10	.08	Two-thirds full size	do	do	Centers green	Not uniform in size	Do.
July 13	do	18	.04	do	do	do	do	Nearly full size	Glossy.
July 15	do	20	.03	Three-fourths full size	Turning yellow	Doughy	White	do	Greenish brown.
July 17	do	22	0	do	do	do		Full size, not completely filled.	All colors.
July 19	do	22	0	Fourth-fifths full size	do	do		do	Do.
July 21	Turning yellow	22	0	do	do	do	Green	Full size	Reddish brown.
July 23	do	22	0	Full size	do	do	do	do	Do.
July 25	do	22	.02	do	do	do	Turning brown	do	Do.
July 27	do	22	0	do	do	do	do	do	Brown.[3]
July 29	do	22	0	do	Nearly brown	Hard	Brown	do	Dark brown, very few dark green.
July 31	Yellow, 90 per cent	22	0	do	do	do	do	do	Do.
Aug. 2	do	22	0	do	Brown	do	do	do	Do.
Aug. 4	Yellow, 95 per cent	22	0	do	do	do	do	Uniform in size	Dark brown.
Aug. 6	do	22	0	do	do	do	do	do	Do.[4]
Aug. 8	do	22	0	do	do	do	do	do	Do.[4]

[1] The flax averaged 32 inches in height at maturity. The first blossoms were noticed on June 27.
[2] Leaves also green.
[3] Reddish tinge gone by July 27.
[4] One-tenth of 1 per cent black.

The flax, after being pulled, was spread out to dry for a day or two, then tied into bundles, and the seed bolls were wrapped in a sack to prevent any loss of seed. The bundles were stored in a dry room until late in the summer, when they were carefully threshed. The straw was then retted for 14 days in cold water. The retting was very slow, and it is certain that overretting did not occur, the length of time being primarily due to the lateness of the season. As the samples were rather small, they were well braked upon a small flax brake and the shives shaken out. Weighings of the fiber were then made, after which it was hackled, and the hackled fiber was used in the chemical determinations. Small amounts of the hackled fiber were cut into 15-centimeter lengths, conditioned at 65 per cent humidity, and weighed to one ten-thousandth of a gram. These, after reconditioning at 65 per cent humidity, were broken upon a hand-operating cloth-testing machine. The breaking strength in kilograms per gram of fiber was then determined for the length, 15 centimeters.

In the earliest harvested samples the seed was very carefully cleaned by hand, as the seeds were very light and an ordinary fanning mill would have blown them away. The other samples were cleaned by hand also, but not so much care was required, as the seeds were all mature.

As stated earlier, several rows of flax were skipped in harvesting and pulled on the last day, August 5. The yields for the different harvesting dates were figured in percentages of those for the skipped rows, which served as checks. The percentages were determined by dividing the actual yields by the corrected yields. The corrected yields were obtained by the method of straight-line interpolation between checks.

Gompertz's growth curves, referred to by Prescott (*16*), were fitted to these percentages as well as to the actual yields, as shown in the figures. The growth curves were fitted to the data by the method of grouping. The straw and fiber yields did not follow such a growth curve, so the best straight line was fitted to these data to show the lines of trend.

In 1927 a more extensive test was made on the time to harvest. Instead of harvesting one sample every day as in 1926, 10 samples were harvested from different sections of a large field every other day for 35 days and in addition on every fifth day an extra large area of flax was pulled. The individual samples taken every other day were drill rows 20 feet long. The next pulling, two days later, was the adjacent drill row, until 18 rows had been harvested side by side. Sections where the 18 rows were pulled were labeled from A to J, inclusive, and were widely separated in the field. The samples were dried in a greenhouse and then carefully wrapped separately in cheesecloth to prevent loss of seed until they could be threshed. The threshing of all samples was done by picking the seed bolls off by hand and crushing them between the fingers. All seeds that did not pass through a 1.651-millimeter diameter screen were picked out from the chaff with forceps and the seed weight or yield recorded. This proved to be a tedious procedure requiring a great deal of time, as there was a very large number of small, immature seeds. The straw, after weighing, was retted in warm water in three separate rets in which the straw from the first six, middle six, and last six

days of harvest, respectively, was retted together. The first and the second rets were normal, but the straw from the last six days of harvest did not ret well and remained in the water, which was changed a few times, for a month, and even then was not well retted but had lost considerably in weight. It was afterwards discovered that the retting tank used for retting the samples from the last six days contained some copper, which undoubtedly reduced bacterial growth.

The scutching was done upon a special Grant scutcher. This machine was designed for small-plot work, and its work was uniform and accurate. It had been found by previous scutching tests on samples of similarly treated and retted straw that the probable error for the average percentage of scutched fiber of 10 samples of similar straw worked on the Grant scutcher is less than one-half of 1 per cent. The fiber strength was determined from the scutched fiber in 1927, the method used in 1926 being followed.

In 1928 harvesting was done on only four separate days, which represented different stages of maturity. Each day that pullings were made the flax was divided into two separate lots. One lot of flax was spread loosely on wire screens in a cool barn to cure. The other lot of the same pulling was cured rapidly in a greenhouse. The temperature in the greenhouse was several degrees warmer than the atmosphere outside, although the windows of the greenhouse were open at all times. The flax, after being completely cured, was treated in a manner similar to that in 1926 and 1927. Special effort was made in 1928 to ret the flax similarly. The straw had its roots and panicles removed before retting. Samples representing all the treatments were retted together in a large glass jar. The ret required approximately eight days at a room temperature of 23° C.

In general the results in 1926, 1927, and 1928 agree very well. The general shape of the growth curves and the lines of trend that have been fitted each year to the data agree in nearly every respect.

YIELD OF SEED

Figure 1 shows graphs of the actual yields of seed in grams and the actual germination percentage of the seed of flax harvested at successive intervals in 1926 and 1927, to which Gompertz's growth curves have been fitted to show the trend of the results. The increase in yield of seed is fairly rapid, the maximum yield being reached about three weeks after full bloom. Tables 1 and 2, which present data on the appearance of the plant and condition of the seed on different harvest days, show that the seed is past the dough stage and is hard and brown at the end of the third week of harvest.

The data agree with those of previous workers in regard to the increase in the weight of the seed, but with the exception of Dillman (*9*) cover a greater period of time and cover it more intensively, as others have studied the seed from only three to five separate days, representing different stages. The growth curve for the increase in seed weight follows the same trend as the curve for the actual yield of seed, as would be expected. This is due to the fact that the increase in the yield (weight) of the seed is not so much an increase in the actual number of seeds as in the size and weight of the individual seeds.

Figure 2 shows that the percentage of oil [4] in the seed reaches its maximum very early and that the immature seeds contain a fairly

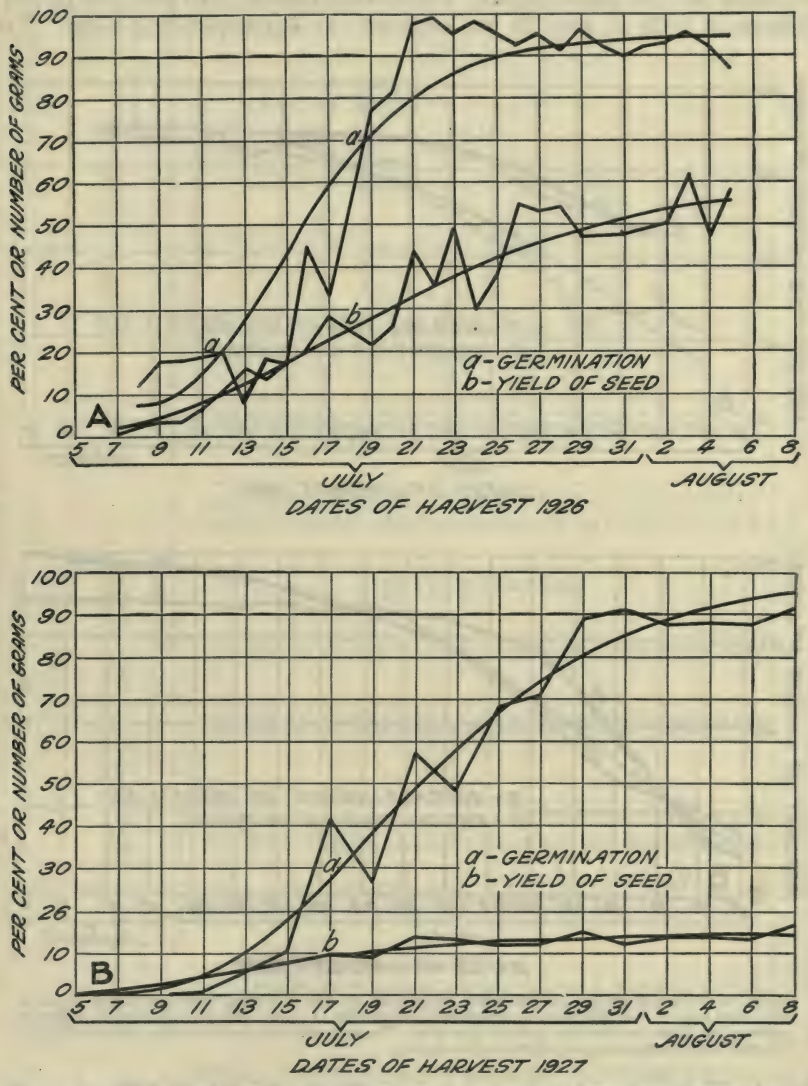

FIGURE 1.—Yield of seed in grams and percentage of germination of seed of flax harvested on different days in 1926 (A) and in 1927 (B). Gompertz's growth curves are fitted to show the trend of the data. The yield of seed in 1926 is from one plot, each plot being a drill row of flax 30 feet long, or $\frac{1}{356}$ of an acre. The yield of seed in 1927 is the average yield of 10 separate plots harvested each day. Each plot was a drill row of flax 20 feet long, or $\frac{1}{6534}$ of an acre

high percentage of oil. The percentages in 1926 for the immature seeds are higher than in 1927, which tends to indicate that the harvest began at a later stage in 1926 than in 1927.

[4] Oil analyses of the seed were made by D. A. Coleman and H. C. Fellows, of the Bureau of Agricultural Economics, U. S. Department of Agriculture.

GERMINATION OF SEED

That the pulling began earlier in the plant's growth in 1927 is also indicated by the germination, which began with zero per cent in 1927 whereas in 1926 it was 12 per cent on the corresponding date. The

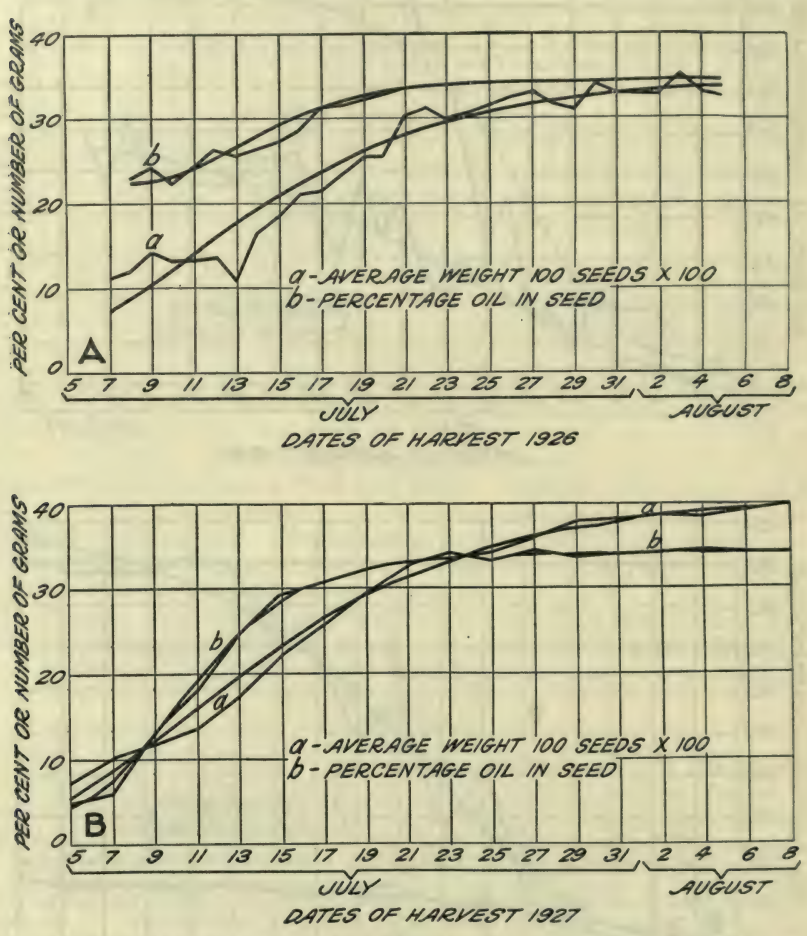

FIGURE 2.—Average weight per 100 seeds, multiplied by 100, in grams, and percentage of oil in air-dried seed of flax harvested on different days in 1926 (A) and 1927 (B). Gompertz's growth curves are fitted to show the trend of the data. The seed was obtained from one plot in 1926 and in 1927 from 10 separate plots harvested each day

actual germination data are shown in Tables 3, 4, and 6 for the years 1926, 1927, and 1928, respectively. The germination of the seed agrees with the results of several workers and shows that good germination may be obtained comparatively early in the harvest period from seed that is not fully mature, but which undoubtedly matures somewhat after pulling, while curing on the straw.

TABLE 3.—*Actual yields of straw, fiber, and seed and chemical determinations made on the fiber and seed of plots of flax harvested on different days in 1926* [1]

Date harvested	Straw			Seed		Germination		Fiber							
													Cellulose		
	Unthreshed	Threshed	Retted	Total weight	Weight per 100 seeds	Total seeds	Heavy seeds [2]	Oil [3]	Weight	Water	Ether extract [4]	Alcohol extract [4]	Alkali insoluble	Alkali soluble	Total
	Grams	*Grams*	*Grams*	*Grams*	*Gram*	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
July 7	447	378	283	0.78					85.1						
July 8	398	324	246	2.66	0.1190	12		22.93	67.2	6.39	2.41	4.05	63.71	26.14	89.85
July 9	483	388	292	3.35	.1408	18		24.07	81.5						
July 10	420	337	264	3.85	.1320	18		22.33	76.8						
July 12	435	355	270	10.22	.1372	20		26.21	82.6	6.08	2.38	3.92	67.14	26.40	93.54
July 13	481	383	297	16.14	.1060	8		25.59	82.5	5.96	2.13	3.65	56.86	27.71	84.57
July 14	432	345	265	13.34	.1661	18		26.32	71.9						
July 15	447	358	267	16.82	.1853	17		27.11	72.3	6.20	2.18	3.34	47.23	32.22	79.45
July 16	443	346	260	20.60	.2110	45		28.63	75.4						
July 17	486	381		28.49	.2143	33		31.08	88.4	5.93	2.28	3.41	40.74	32.84	73.58
July 19	351	279	214	21.82	.2540	77		32.22	62.4						
July 20	400	317	255	25.97	.2558	81		32.87	64.1	6.28	2.16	3.21	49.09	29.67	78.76
July 21	438	340	274	44.03	.3020	97	100	33.73	79.6	6.67	2.28	3.26	52.16	28.72	80.88
July 22	401	320	248	35.22	.3124	99	99	34.00	73.6	6.28	2.11	3.28	62.94	26.42	89.36
July 23	422	320	263	48.91	.3028	95	100	34.17	69.0	6.77	2.11	3.30	62.25		
July 24	344	286	226	30.16	.3070	98	100	34.14	77.6						
July 26	493	377	313	54.91	.3257	93	99	34.33	77.4	6.57	2.17	3.21			
July 27	429	323	254	53.15	.3315	95	100	34.43	81.4						
July 28	444	343	291	54.10	.3177	91	99	34.33	83.4						
July 29	404	308	258	47.05	.3125	96	98	34.32	91.9						
July 30	404	310	258	47.13	.3403	92	97	34.37	82.4						
July 31	426	318	255	49.20	.3296	90	95	34.45	75.4	5.36	2.07	3.35			
Aug. 2	433	341	283	50.45	.3290	93	99	34.48	82.2	4.67	2.45	3.70			
Aug. 3	423	307	256	61.88	.3510	95	91	34.50	74.5						
Aug. 4	351	261	222	46.60	.3300	92	95	34.50	61.4						
Aug. 5	428	320	268	57.55	.3267	87		34.40	77.8						
(5)	413	326	266	45.74	.3092	87		34.48	65.8						
(5)	429	323	271	56.67	.3362	92		34.42	86.3						
(5)	422	330	281	47.45	.3358	88		34.50	79.4						
(5)	407	335	276	35.56	.3068	85		34.38	79.4						
(5)	371	295	247	38.78	.3228	89		34.47	78.4						
(5)	479	373	317	58.88	.3328	82		34.45	94.2						
(5)	441	337	285	53.93	.3294	90		34.43	90.7						
(5)	343	268	223	40.71	.3418	91		34.29	74.9						
(5)	302	302	253	49.40	.3356	88		34.25	84.9						
(5)	392	294	248	51.38	.3158	87		34.51	65.4						

[1] Each plot was a drill row of flax 30 feet long, or $\frac{1}{356}$ of an acre.
[2] The germination of only heavy seeds, obtained by cleaning with a fanning mill.
[3] Wet basis. The seed used in the oil analysis had 5 to 5.5 per cent moisture.
[4] Dry basis.
[5] Rows used to check soil heterogeneity; harvested Aug. 5.

TABLE 4.—*Average yields of 10 samples of flax harvested in 1927*

Date harvested	Straw		Seed				Fiber		
	Unthreshed	Threshed	Total weight	Weight per 100 seeds	Germination	Oil [1]	Weight	Strength [2]	Hackling [3]
	Grams	*Grams*	*Grams*	*Grams*	*Per cent*	*Per cent*	*Grams*	*Coefficient*	*Per cent*
July 5	152	123	0.29	0.0713	0	4.96	27.17	137.3	42.77
July 7	157	118	.96	.1023	0	6.15	25.98	130.2	32.61
July 9	186	134	2.54	.1167	0	13.27	32.37	163.3	37.21
July 11	189	139	4.26	.1367	.6	18.10	32.07	148.8	35.89
July 13	183	129	6.06	.1756	5.6	24.84	33.22	142.2	37.64
July 15	167	121	7.75	.2230	10.2	29.39	28.04	123.0	39.89
July 17	175	125	9.68	.2570	42.0	30.72	34.10	178.8	46.87
July 19	166	117	9.05	.2955	27.2	32.29	30.06	207.8	46.21
July 21	205	144	13.92	.3282	57.4	32.81	36.28	225.1	43.96
July 23	206	147	13.69	.3341	48.7	34.07	35.37	213.5	38.53
July 25	175	121	12.56	.3433	68.2	33.21	30.29	207.9	45.65
July 27	169	122	12.52	.3607	71.1	34.53	29.26	179.2	40.72
July 29	192	140	15.01	.3784	89.2	33.65	36.84	151.4	28.89
July 31	183	141	12.29	.3827	90.8	34.07	34.90	149.1	30.49
Aug. 2	197	147	13.81	.3870	87.6	34.13	32.86	167.9	24.97
Aug. 4	209	151	13.86	.3843	88.1	34.40	36.35	158.9	24.54
Aug. 6	191	139	13.65	.3902	87.8	34.11	29.03	133.6	25.31
Aug. 8	224	163	16.41	.3962	91.4	34.32	35.17	173.3	21.19

[1] The percentage of oil in the seed represents an average of two determinations on the bulk of the air-dried seed of the 10 samples.

[2] The fiber strength is in kilograms per gram of fiber 15 centimeters in length. The probable errors of the strength are low; e. g., July 7, 128.40±6.07; July 21, 225.92±5.76; Aug. 4, 155.49±6.25. Each plot was a drill row of flax 20 feet long, or 1/6534 of an acre.

[3] The hackling percentage represents one determination on the 10 samples of fiber together.

The germination in 1927 (fig. 1, B) does not show such a marked increase at the beginning of the harvest as it does in 1926. (Fig. 1, A.) It is believed that there were probably two reasons. In 1927 a great deal more care was used in picking out seeds, including the mature ones, so that the percentage of germination in the early stages was lowered because of the larger proportion of immature seeds. The average germination of 1,000 seeds harvested each day from July 17 to 27, 1927, and tested later, was variable. Before this time it increased fairly uniformly and afterwards it was relatively constant. (Fig. 1, B.) It is not known exactly why these few days showed such a variability. Identical results were secured by a second germination trial. The only explanation that may be given is that when the straw was cured in a greenhouse the temperature was very warm. By reference to the United States Weather Bureau reports it was found that July 19 and 23 were clear, sunshiny days and that July 17 and 21 were cloudy and rainy. It is probable that the temperature and other

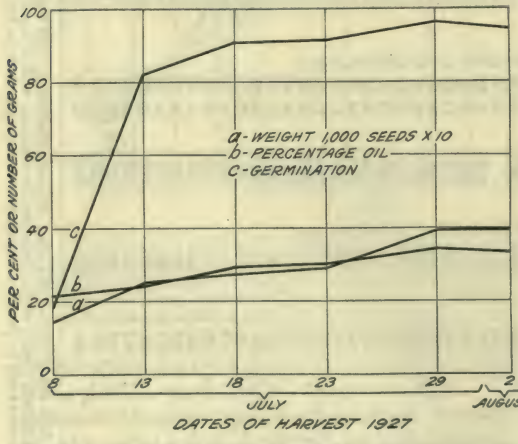

FIGURE 3.—Data from six large areas of flax harvested in 1927. The areas were of unequal size. The seed after threshing was cleaned on a fanning mill

physiological conditions in the greenhouse reduced the germination of the seed harvested on July 19 and 23. In Table 5 and Figure 3 data are given from the large samples of flax harvested at five different periods in 1927, in which the seed was cleaned with a fanning mill, removing a large number of light, immature seeds. The germination test of this seed showed a very high percentage of germination much earlier than the hand-picked samples harvested every other day in 1927, the results of which are shown in Table 4. The light seeds present in all early harvested samples partly account for the imperfect germination, as the germination data are from seeds selected at random. Samples of seed taken from July 21 to August 4, 1926, inclusive, showed a germination that averaged 99 per cent when cleaned of light seeds by an air current. This was in some cases a 10 per cent higher germination than that obtained from seeds selected at random and not fanned. (Table 3.)

TABLE 5.—*Data from large samples of flax harvested at different periods in 1927*

Date	Harvest stage	Germination	Weight per 100 seeds	Oil in seed [1]	Straw after retting	Fiber in retted straw	Quality of fiber
		Per cent	*Gram*	*Per cent*	*Per cent*	*Per cent*	
July 8	Green	19.6±1.4	0.1481±0.0031	21.63	79.17	28.90	Best of all samples; softest sample.[2]
July 13	do	81.4±1.1	.2517± .0014	23.92	75.25	24.34	Good.
July 18	Green to yellow.	90.8± .7	.2760± .0038	29.15	76.06	22.06	Fair; medium strength.
July 23	Yellow	91.2± .9	.2910± .0062	30.14	71.85	22.46	Fair; weakest of all samples.
July 29	do	96.4± .4	.3949± .0023	34.12	75.30	21.94	Harsh; fair strength.
Aug. 2	Dead ripe	94.4± .7	.3942± .0024	33.03	75.30	22.85	Harsh; strongest of all samples.

[1] The oil percentage of the air-dried seed was determined by the chemistry experiment station, Michigan State College.
[2] The fiber obtained on July 8 was judged the best of the six different days by the Smith & Dove Manufacturing Co., Andover, Mass.

Reports on the germination of the seed in 1928 are very interesting. The data given in Table 6 show how well the very immature seed will germinate when left on the straw and the straw is allowed to cure slowly. Only 7.3 ± 0.8 per cent of the seed from straw pulled on July 14 and cured in the greenhouse germinated, while 61.3 ± 2.0 per cent of the seed from the same sample of straw cured in a barn germinated.

TABLE 6.—*Data from flax harvested on different days in 1928 and cured in a cool barn or in a warm greenhouse*

Date of harvest	Harvest stage	Where the straw was cured	Weight per 100 seeds	Germination of seed	Straw after retting	Fiber of retted straw	Fiber strength [1]	Hackling	Ether extract [2]	
									Straw	Fiber
			Gram	*P. ct.*	*P. ct.*	*P. ct.*	*Coefficient*	*P. ct.*	*P. ct.*	*P. ct.*
July 7	Full bloom	In shade	[3]0.0846	[3]4.7	80.97	27.46	229.9±6.6	68.89	------	------
July 14	Late green	do	.1879±0.0047	61.3±2.0	82.65	24.43	243.5±8.5	64.06	------	------
July 20	Yellow ripe	do	.2378± .0014	82.6± .5	84.31	25.94	279.6±7.3	73.02	------	------
Aug. 3	Full ripe	do	.4037± .0036	89.6± .7	84.25	26.92	250.6±5.4	73.26	------	------
July 7	Full bloom	In sun	[3].0814	0	82.70	28.59	190.4±6.8	56.00	1.41	2.15
July 14	Late green	do	.1568± .0004	7.3± .8	81.17	25.57	226.5±9.0	62.20	1.65	2.19
July 20	Yellow ripe	do	.2495± .0026	15.3± .4	83.06	27.96	288.4±7.6	73.15	1.64	2.38
Aug. 3	Full ripe	do	.3991± .0013	93.6±1.2	85.72	28.45	243.9±8.3	70.10	1.58	2.82

[1] Kilograms per gram of fiber, length 15 centimeters.
[2] Dry basis.
[3] Too few seeds for replicate test.

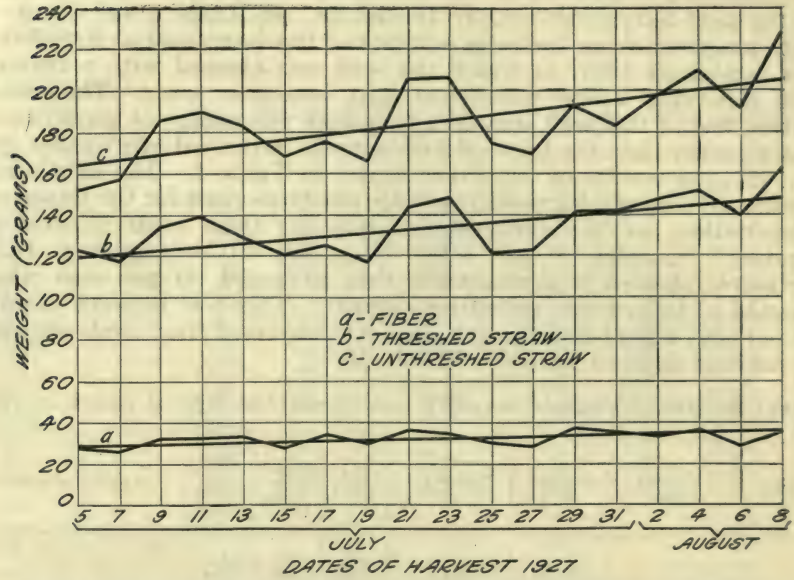

FIGURE 4.—Actual average yield (in grams) of unthreshed straw, threshed straw, and fiber from flax harvested on different days in 1927. Each day's yield is the average of 10 separate plots. The trends are shown by the best straight line fitted to the data. Each plot was a drill row of flax 20 feet long, or $\frac{1}{6534}$ of an acre

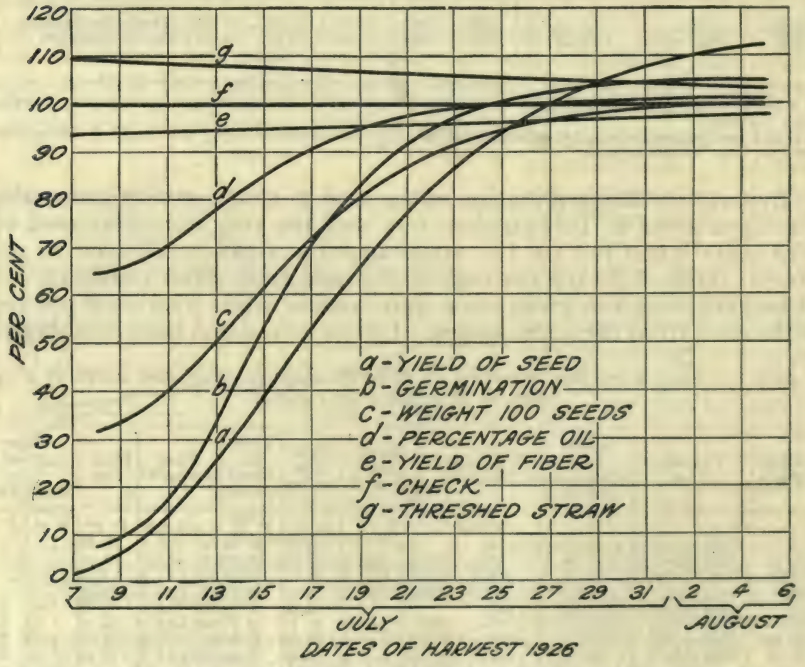

FIGURE 5.—Trends of data for different days of harvest in 1926 given as percentages of the last day's harvest taken as equal to 100 per cent

YIELD OF STRAW

The actual yields of straw in 1926 and 1927 are given in Tables 3 and 4, respectively, while that for 1927 is shown graphically in Figure 4. Figures 5 and 6 show the trend of the corrected yields of straw in 1926 and 1927, respectively. In 1926 (fig. 5) the yield of threshed straw decreased slightly, but the decrease was not significant, being only 6.43 ± 9.37 per cent. However, in 1927 the lines of trend (figs. 4 and 6) show a significant increase in the yield of both the unthreshed and threshed straw as the plant matures. The increase is partly accounted for by the fact that the seed develops on the plant with a slight extension of the panicle; but the plant also must increase in weight, as the threshed straw, too, shows an increase as the plant

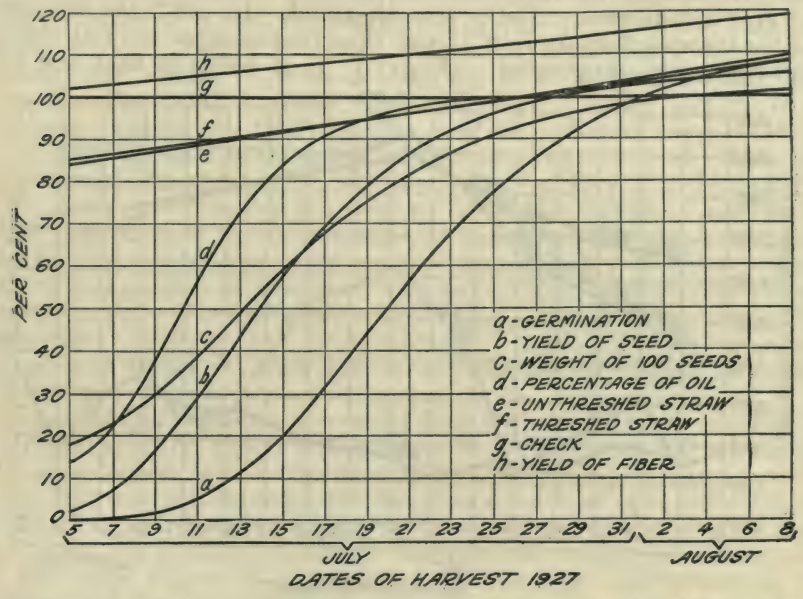

FIGURE 6.—Trends of data for different days of harvest in 1927 given as percentages of the data for the harvest of August 6 taken as equal to 100 per cent

matures. The increase in weight in the unthreshed straw is slightly greater than in the threshed straw, as is shown by the slope of the lines of trend. (Fig. 6.) It is possible that the yields of straw might follow a growth curve if the weights were taken from the seedling stage to maturity, but the results obtained here on the weights of plants after flowering had started did not seem to indicate or warrant the fitting of anything but a straight line. The increase in the weight of the straw apparently nearly reaches its peak at full bloom, and after that the increase is gradual and nearly constant.

YIELD OF FIBER

The yield of fiber in each of the two years that it was studied is shown, by lines of trend, to increase as the season advances. In 1926 the increase in the trend of fiber weight from the first to the last day is 3.65 ± 10.9 per cent (fig. 5), which is not significant; and in

1927 the increase in the trend of fiber weight from the first pulling to the last pulling is 17.79 ± 9.57 per cent (fig. 6), which is not significant. A significant increase would have agreed with what has been generally supposed from commercial results.

QUALITY OF FIBER

Although the yield of fiber increased somewhat, the quality did not improve very much except that in all three years the strength of the fiber, which is an important factor, increased with the lateness of the harvest. In 1926 the trend of the increase in strength throughout the period of harvest was gradual, but on some days the actual data varied considerably from the trend. Because of this variability in 1926, the average strength for 3-day periods was plotted (fig. 7), and the graph indicates a fairly smooth trend. In 1927 the strength of fiber increased up to July 21 and then decreased as the full-ripe or dead-ripe stage progressed. (Fig. 7.) It is believed that the low

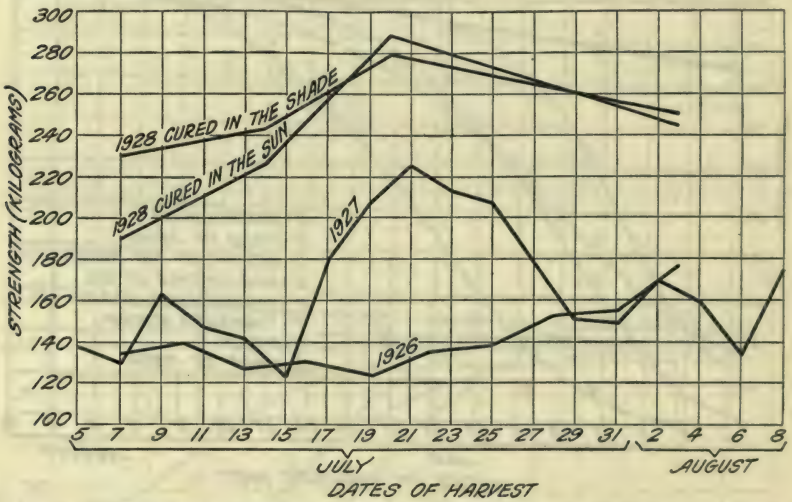

FIGURE 7.—Strength of fiber estimated as kilograms per gram of fiber 15 centimeters in length for different days of harvest in 1926, 1927, and 1928. In 1928, after harvesting a sample of flax, the sample was divided and one half of it was cured in the sun and the other half was cured in the shade

strength of fiber shown by the last six days' pullings is due somewhat to the poor retting; such a decrease is indicated, however, by the fact that the pullings of the middle six days, which were retted together, show an increase followed by a decrease that fits well with the later data. The scutched fiber tested for its strength was first conditioned under a constant 65 per cent humidity before weighing, after weighing, and before breaking.

In 1928 the strength of the fiber was low in the early stages of harvest, high in the middle period, and moderately high at the last harvest. These data are somewhat similar to those obtained in 1927. The two years together indicate that the strength may increase throughout the yellow-ripe period of harvest, later reach a maximum, and then decrease slightly during the full-ripe period. In 1928 the fiber after scutching was green in all samples of straw

cured in the shade and creamy yellow in all that had been cured in the sun. The fiber from the first two harvests was much finer and softer than that from the last two harvests.

In 1926 no record was kept of the hackling percentages, but in 1927 and 1928 these were recorded (Tables 4 and 6), and the percentages of hackled "line" were greatest in the middle or yellow-ripe stage and in the full-ripe stage. The results indicate that a small decrease in the hackling percentage may occur after the yellow-ripe stage, but further work is necessary to substantiate this. These percentages of hackling might be low in 1927 compared with the ordinary percentages of flax hackling, but the tow obtained in scutching is not usually considered in the hackling percentage. In the present case the hackling percentage represents the hackled line from the total yield of fiber. It is necessary to express it in this manner because the Grant scutcher used did not separate the line from the tow. The 1927 fiber did not appear consistent in the amount of "nature" [5] present, although there was not a great difference. The early samples contained slightly more nature than the later samples and this, with the good strength and good hackling percentage of the middle period of harvest, helps to prove that this stage is more favorable than the later stage for fiber of good quality.

To determine whether the fiber at the earlier stages of harvest is oilier than that at the later stages, as has been reported, both ether and alcohol extractions were made of samples of flax harvested on different days, as well as of the straw from which the fiber was retted and scutched. The data given in Tables 3 and 6 show very small differences between the early-harvested and the late-harvested samples, so that it is impossible to say whether the earlier harvested are oilier.

A number of cellulose determinations were made upon samples of fiber harvested on different days in 1926. (Table 3.) The hackled fiber was put in clear ammonium hydroxide (NaOH) solution, which separated out the soluble celluloses from the insoluble cellulose (*6*) under the particular conditions. The alkaline solution of cellulose contained the lignified cellulose, which is said to increase in amount in the later stages of harvesting. Besides the determinations of soluble and insoluble cellulose, data are given for the total cellulose in 1 gram of fiber. (Table 3.) The data in Table 3 are too few to give conclusive evidence of any increase or decrease in the cellulose content. The small differences may have been caused by nonuniform small samples of fiber, averaging 0.35 gram per sample, and more probably by the method of determination, which is not standardized for flax. As the results gave such small differences without a natural trend, the work was not repeated nor was a method worked out that applied especially to the problem.

The data obtained apply only to the green-ripe and yellow-ripe flax, as no determinations were made, for the full-ripe stage. They give low alkali-insoluble cellulose content and high alkali-soluble cellulose content in the early yellow-ripe period. Further work is needed on the cellulose content of flax fiber at different stages of

[5] A flax spinner's term used to designate quality, including feel, softness, life, resiliency, elasticity, and oiliness.

maturity, in order to draw more definite conclusions and to cover all three stages of harvesting.

Alpha-cellulose determinations were made upon six samples of flax fiber grown in 1927. The method used was that reported by the alpha-cellulose committee of the American Chemical Society.[6] The alpha-cellulose determinations for flax pulled on different days, expressed as percentages of dry weight of the fiber, are as follows: July 8, 76.5; July 13, 76.1; July 18, 76.3; July 23, 78; July 29, 79.5; and August 2, 80. These cover all three periods of harvest and indicate a small increase in the alpha-cellulose content of the fiber as the plant goes from the yellow-ripe stage to that of full-ripe maturity. The alpha-cellulose determinations made in 1927 are much higher than the alkali-insoluble cellulose determinations made in 1926. This is largely due to the difference in the method of determination and probably only slightly due to the better cleaning in the scutching and hackling in 1927.

DISCUSSION

Table 7 shows the actual figures of yields in 1927 as percentages of the yields of August 6. This date was selected as the standard, since it was near the end of the period of harvest and did not have a few abnormal high yields as found on August 8. All seven characters studied show an increase as the flax matures. The fiber weight appears high throughout, on account of a low yield of fiber on August 6. The growth curves and lines of trend shown in Figure 6 were calculated from the data in Table 7.

TABLE 7.—*Percentage yields in 1927 obtained by determining the average of 10 samples of flax for each harvest day as percentages of the average yield of August 6* [1]

Date	Straw		Seed				Fiber weight
	Unthreshed	Threshed	Total weight	Weight per 100 seeds	Germination	Oil [2]	
July 5	79.58	88.35	2.10	18.26		14.54	93.59
July 7	82.19	85.04	7.00	26.21		18.03	89.49
July 9	97.38	96.62	18.60	29.90		38.90	111.50
July 11	98.95	99.56	31.20	35.03	0.68	53.06	110.47
July 13	95.81	92.45	44.40	45.00	6.37	72.82	114.43
July 15	87.43	86.62	56.77	57.15	11.61	86.16	96.59
July 17	91.62	89.64	70.92	65.86	47.83	90.06	117.46
July 19	86.91	84.18	66.30	75.73	30.97	94.66	103.54
July 21	107.32	103.30	102.00	84.11	69.59	96.19	124.97
July 23	107.85	105.89	100.33	85.62	55.35	99.88	121.83
July 25	91.62	87.13	92.00	87.98	77.67	97.36	104.34
July 27	88.48	87.99	91.71	92.43	80.97	101.23	100.79
July 29	100.52	100.93	109.96	96.97	101.59	98.65	126.90
July 31	95.81	101.65	90.07	98.07	103.41	99.88	120.22
Aug. 2	103.14	105.89	101.17	99.17	99.77	100.06	113.19
Aug. 4	109.42	108.55	101.56	98.48	100.34	100.85	125.21
Aug. 6	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Aug. 8	117.27	117.03	120.20	101.53	104.10	100.62	121.15

[1] The average yields of Aug. 6 were taken as 100 per cent.
[2] The percentage of oil in the seed was determined for only two samples for each day.

In Table 8 a comparison is made between the data for the different days and those for July 21. This day was used for purposes of comparison because it seemed to mark the turning point of the

[6] RITTER, G. J., CHAIRMAN. MODIFIED METHOD NO. 4 FOR THE DETERMINATION OF ALPHA CELLULOSE REPORTED BY THE ALPHA-CELLULOSE COMMITTEE OF THE AMERICAN CHEMICAL SOCIETY. [Unpublished.]

growth curves for a number of the characters. Table 2 shows that the condition of the plants on July 21 was very close to that when fiber flax is considered ready for harvest. The comparison was made by using Student's method (*2*) which gives odds for the significance of the differences in the data. Odds greater than 40 to 1 are often selected as representing significant differences and in Table 6 (odds more than 40 to 1 or less than 1 to 40) it is shown that on July 21 yields were greater than those on earlier days for germination and weight per 100 seeds, but that these increase significantly after July 21. The seed yield (and possibly the percentage of oil, had calculation been feasible) did not increase after July 21 but was significantly low before that date.

The data from the unthreshed and threshed straw and the fiber are somewhat variable. The standard, July 21, is in general equal to the period following and slightly better than the earlier period. Tables 7 and 8 indicate that flax harvested as early as July 21 gave yields that were near or at the maximum for all the characters studied except the germination of the seed and the weight per 100 seeds.

TABLE 8.—*Odds* [1] *showing significance of difference between average daily yields* [2] *and those of July 21 used as a standard* [3]

Date	Straw		Seed			Fiber weight
	Unthreshed	Threshed	Weight	Germination	Weight per 100 seeds	
July 5	61:1	6:1	9,999:1	9,999:1	9,999:1	344:1
July 7	3,332:1	1,110:1	9,999:1	9,999:1	9,999:1	9,999:1
July 9	61:1	22:1	9,999:1	9,999:1	9,999:1	81:1
July 11	8:1	2:1	9,999:1	9,999:1	9,999:1	61:1
July 13	132:1	61:1	9,999:1	9,999:1	9,999:1	61:1
July 15	666:1	344:1	9,999:1	9,999:1	9,999:1	9,999:1
July 17	13:1	8:1	163:1	100:1	9,999:1	2:1
July 19	61:1	81:1	908:1	3,332:1	1,428:1	81:1
July 21	(4)	(4)	(4)	(4)	(4)	(4)
July 23	1:1	1:2	1:1	18:1	1:2	2:1
July 25	13:1	18:1	8:1	1:37	1:48	18:1
July 27	156:1	100:1	8:1	1:163	1:327	666:1
July 29	3:1	1:1	1:3	1:9,999	1:9,999	1:1
July 31	18:1	1:1	4:1	1:9,999	1:9,999	1:1
Aug. 2	3:1	1:2	1:1	1:9,999	1:9,999	49:1
Aug. 4	1:2	1:5	1:1	1:9,999	1:4,999	1:2
Aug. 6	6:1	2:1	1:1	1:9,999	1:2,499	9,999:1
Aug. 8	1:5	1:10	1:22	1:9,999	1:9,999	1:1

[1] Obtained by Student's method (*2*).
[2] See Table 5.
[3] Odds of more than 40 to 1 (or less of than 1 to 40) may be considered as showing the results were not due to chance. Odds were not determined for the percentage of oil in the seed, as only two oil determinations were made for each day.
[4] Used as the standard of comparison.

Thus it has been shown that a number of characters in fiber flax reach simultaneously a maximum increase. These data would be of little value without a knowledge of their close correlation with the appearance of the plant at different stages. If the maximum yield of fiber and seed, the percentage of germination, etc., can be associated with the plant's morphological appearance, then the proper stage for pulling may be recognized in the appearance of the crop.

Tables 1 and 2 give data on the color of the stems, presence or absence and color of the leaves, number of flowers, size and color of

the bolls, and character of the seeds from day to day. Each year the harvesting started before flowering was over, when there were a few seed bolls about one-half their normal size and an average of two flowers per stem still in bloom. This stage is reached a little earlier than fiber flax is pulled in the United States and is therefore a good period at which to begin. According to the tables, the stems had turned yellow and the leaves had fallen off for two-thirds of the distance up the stems, about July 26 or 27. Comparing the condition of the seed bolls in the tables, it is seen that the harvest might have started as early as July 21, since the required number of bolls were then yellow. However, a few days later 50 per cent of the bolls would have turned from yellow to light brown, and thus this stage coincides in 1926 and in 1927 with the time when the leaves have fallen from the stems and the latter have turned yellow. Hence in central Michigan the harvest should start about July 26 or whenever the condition of the plants in the fields corresponds to the condition normally reached on that date. This date corresponds very closely to the average seasonal time of harvest at East Lansing, Mich., but is a week or 10 days earlier than the seasonal conditions in the "thumb region," the principal fiber-flax area of Michigan. There the harvest begins about August 1. In Oregon, where fiber flax is grown, the best flax is usually all pulled before August 1.

In Tables 3 and 4, which give the yields and analyses, the germination, percentage of oil yield, and weight per 100 of the seed are all low and on an upward trend before July 21. By that date some of the conditions have reached a maximum or very nearly a maximum, and the others increase only slightly thereafter. It would appear that as far as the seed is concerned the germination, percentage of oil, and weight per 100 seeds are all at their maximum by July 26 or a few days earlier. Though the trend of the total yield of seed still tends to rise after July 25, the rise is slight and mathematically insignificant (17.88 ± 12.52 per cent (fig. 7) in 1926); and it would be best to begin harvesting at about this time, especially if the acreage is large enough to make the work extend over several days. If the farmer has acreage requiring only one or two days to harvest, then a day or two later might be best as far as the germination and weight of the seeds are concerned.

Since the oil and cellulose content of the fiber show little or no correlation with the time of pulling, and only the strength of the fiber increases with later pulling, with a little loss in "nature," the data indicate that the best time to harvest, as far as the fiber is concerned, is at the yellow-ripe stage, or in the present case about July 25 or 26.

Pulling machines used for harvesting fiber flax in recent years seem to work better with flax full ripe to dead ripe. It may be possible to improve the machines so that they will work more efficiently in harvesting flax at earlier stages. Aside from the fact that the crop may yield a fiber of better quality if harvested early, it is usually desirable to harvest as early as possible to avoid danger of losses from bad weather, lodging, and diseases and to allow more time for the following processes of threshing, retting, scutching, and hackling, and thus secure a quicker financial return. In some localities, if the flax is harvested late, it is impossible to ret it under natural conditions until the following year.

The data here presented seem to justify the farmers of North America in their practice regarding the time of pulling fiber flax. No more favorable conditions for harvesting can be suggested than those already mentioned. Many farmers do not begin harvesting until the yellow stage of flax is well advanced, and with a large acreage this results in a very overripe condition before the harvest is ended. It would be better to begin harvesting earlier and to raise no more than may be pulled during the yellow-ripe stage.

SUMMARY

In order to determine the proper time to harvest fiber flax, observations were made during the summers of 1926, 1927, and 1928 with respect to the morphological appearance of the plants as correlated with the yields and certain other specified characters of the straw, seed, and fiber.

Determinations were made of these data on different days of the harvest for each of the three years, and the results are expressed in both tables and graphs. The changes in the various characters from day to day, as well as their relationships to one another, are likewise discussed in detail.

The conclusion is reached that fiber flax should be harvested during the yellow-ripe stage, in order to insure the best results in yield and quality of both the fiber and the seed.

LITERATURE CITED

(1) Anderson, D. B.
1927. A microchemical study of the structure and development of flax fibers. Amer. Jour. Bot. 14: 187–211, illus.

(2) Anonymous.
1908. The probable error of a mean. By Student. Biometrika 6: 1–25, illus.

(3) Barker, M. F.
[192–]. A chemical study of the flax plant. I.—The development of oil in the seed of the flax fibre crop and variations in its character with maturity. Linen Indus. Research Assoc. Mem. 6, 10 p., illus.

(4) ——— and Eyre, J. V.
1923. A chemical study of the flax plant. II.—The variation of the constituents of flax seed with maturity. Linen Indus. Research Assoc. Mem. 15, 11 p., illus.

(5) Bradbury, F.
[1920]. Flax culture and preparation. 154 p., illus. London.

(6) Bray, M. W., and Andrews, T. M.
1923. An improved method for the determination of alpha, beta, and gamma cellulose. Indus. and Engin. Chem. 15: 377–378.

(7) Bredemann, G.
1925. Einfluss der erntezeit auf die beschaffenheit der leinsaat. Faserforschung 4: 234–243.

(8) Bushey, A. L., Puhr, L., and Hume, A. N.
1927. A study of certain physical and chemical characteristics of flaxseed and linseed oil. S. Dak. Agr. Expt. Sta. Bul. 228, 11 p.

(9) Dillman, A. C.
1928. Daily growth and oil content of flaxseeds. Jour. Agr. Research 37: 357–377, illus.

(10) Eyre, J. V., and Fisher, E. A.
1915. Some considerations affecting the growth of linseed as a farm crop in England. Jour. Agr. Sci. [England] 7: [120]–134, illus.

(11) FARGHER, R. G., and WITHERS, J. C.
1922. CHEMICAL CONSTITUENTS OF RAW COTTON. Jour. Textile Inst. Trans. 13: 1–16.
(12) HUTCHINSON, R. J.
1921. FLAX FIBER AND TOW GRADING. Agr. Gaz. Canada 8: 23–24.
(13) ———
1923. REPORT OF THE CHIEF OFFICER OF THE DIVISION OF ECONOMIC FIBRE PRODUCTION. Canada. Rpt. Ministry Agr. 1923: 13.
(14) IVANOW, S.
1912. ÜBER DEN STOFFWECHSEL BEIM REIFEN ÖLHALTIGER SAMEN MIT BESONDERER BERÜCKSICHTIGUNG DER ÖLBILDUNGSPROZESSE. Bot. Centbl., Beihefte (1) 28: 159–191, illus.
(15) OPITZ, K., and PANDER, A. V.
1923. DIE BEEINFLUSSING DER SAATGUTBESCHAFFENHEIT DES LEINS DURCH ERNTEZEIT UND AUSSAATMENGE. Faserforschung 3: 234–240.
(16) PRESCOTT, R. B.
1922. LAW OF GROWTH IN FORECASTING DEMAND. Jour. Amer. Statis. Assoc. 18: 471–479.
(17) RUSCHMANN, G.
1924. OUR PRESENT KNOWLEDGE OF THE RETTING PROCESS OF FLAX. (Transl. by W. A. Davis) Jour. Textile Inst. 15: T61–T74, T104–T114.
(18) TOBLER, F.
1928. DER FLACHS ALS FASER UND ÖLPFLANZE. 273 p., illus. Berlin.
(19) WASHBURN, W. F.
1916. FLAX STUDIES. N. Dak. Agr. Expt. Sta. Bul. 118: 43–48.

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TECHNICAL BULLETIN No. 237 APRIL, 1931

ECONOMIC FACTORS AFFECTING THE BEEF-CATTLE INDUSTRY OF VIRGINIA

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By CHARLES A. BURMEISTER, *Senior Agricultural Economist*, HERMAN M. CONWAY, formerly *Assistant Agricultural Economist, Division of Livestock, Meats, and Wool*, and ALBERT P. BRODELL, *Associate Agricultural Economist, Division of Farm Management and Costs, Bureau of Agricultural Economics*[1]

CONTENTS

	Page
Introduction	1
Importance of grass in the economic program of Virginia cattle producers	2
Early development of the beef-cattle industry in Virginia	3
Rise and decline of United States export trade in cattle and beef	3
Changes in the beef-cattle industry of the United States	4
Distribution of beef-cattle in Virginia	6
Methods of finishing steers	7
Southwest Virginia	7
Shenandoah Valley and north Virginia	9
Methods of selling cattle	9
Buying for future delivery, or contract buying	10
Furnishing stockers and feeders on contract	11
Price determination under the contract system	11
Disadvantages of the contract system	12
Market outlets	13
Richmond	14
Baltimore	14
Lancaster	14
Jersey City	16
Transportation service as a factor in market selection	17
Market destinations of cattle from southwest Virginia	19
Seasonal movements of Virginia cattle	20
Production records of selected shipments of Virginia cattle	23
Description of farms studied	24
Crop production and marketing conditions, 1923 and 1924	27
Methods of compiling costs and limitations of cost data	27
Results of different methods of wintering and fattening steers	29
Marketing records of steers from selected droves	34
Slaughter information regarding cattle followed to market	38
Marketing costs of competing cattle	41
Comparison of cattle prices at Jersey City and Chicago	43
Market grades of cattle	44
Competition for Virginia beef in the New York market	47
Problem of dark-colored beef	51
Trade opinion regarding Virginia cattle	52
Possibilities of increasing returns on Virginia steers by improving the grade	54
Conclusions and recommendations	57
Summary	60

INTRODUCTION

Methods and practices followed by individual livestock producers in their production and marketing operations are usually determined by local conditions and frequently are not subject to material modification. In some instances there is a tendency to adhere to long-established practices, even though developments elsewhere may have created conditions that necessitate readjustments if operations are to be carried on successfully. Frequently such readjustments need be of a minor character only and can be easily effected.

[1] Much of the material presented in this bulletin was obtained in connection with field studies carried on by the Bureau of Agricultural Economics in cooperation with the Virginia Agricultural Experiment Station and the Animal Husbandry Division of the Bureau of Animal Industry. J. J. Vernon, agricultural economist and C. R. Nobles, animal husbandman, represented the Virginia Agricultural Experiment Station in obtaining records of production methods and costs. Acknowledgment is made of valuable assistance rendered by B. F. McCarthy, W. H. Norris, S. B. Ewing, C. M. Harris, J. A. Burgess, and D. J. Slater, of the Division of Livestock, Meats, and Wool of the Bureau of Agricultural Economics, and by E. A. Seaman of the Pennsylvania State Bureau of Markets, in obtaining marketing and slaughter data on shipments of cattle followed to market. Mr. McCarthy made especially helpful contributions regarding the wholesale beef trade and the demand for beef in New York City. Acknowledgment also is made of helpful cooperation rendered by various members of the livestock and meat trade in New York City, Jersey City, Philadelphia, Lancaster, and Boston, by officials of the Norfolk & Western Railway, and by the many livestock producers in Virginia who furnished data and provided facilities for obtaining records.

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This bulletin presents an economic analysis of the production and marketing methods of beef-cattle raisers in Virginia, together with suggestions as to possible readjustments that might be helpful in putting their industry on a more profitable basis. The analysis deals primarily with the beef-cattle industry of Virginia, but the conditions and recommendations set forth apply equally well to the cattle industry in the other States of the Appalachian Mountain area, since conditions throughout this area in general are similar. The bulletin summarizes material obtained in several economic studies conducted by the Bureau of Agricultural Economics and the Virginia Agricultural Experiment Station. In these studies attention was given to the methods, practices, and costs of producing and marketing beef cattle in the principal cattle-producing sections of the State, the suitability of these cattle for trade demands, the market outlets, the competition that these cattle encounter from the cattle of other producing sections, and such other factors as should be given consideration by Virginia cattle raisers when planning their production and marketing operations.

The information was obtained through interviews with cattle producers, local buyers and shippers, slaughterers and meat distributors, and representatives of railroads and market agencies, and through collecting and analyzing production, marketing, and slaughter data on a large number of beef steers produced in the State.

IMPORTANCE OF GRASS IN THE ECONOMIC PROGRAM OF VIRGINIA CATTLE PRODUCERS

The grazing lands of western Virginia constitute one of the principal agricultural resources of that section, inasmuch as they furnish the raw material for the production of more finished products—beef and lamb: Bluegrass grows luxuriantly on the better limestone soils and provides excellent pasture. Much of this pasture land is too steep to be used for growing grain or cultivated crops. Some of it is too stony to be plowed. Even where it is suitable for general farming many of the owners would not plow it because of the relatively high returns that usually can be obtained from grazing.

Bluegrass pastures, to a certain extent, improve with age. It takes from two to five years after the land is once broken to obtain a well-developed sod. Some of the best pastures are reported to have stood for 50 years or more, and they will sustain as many cattle or sheep, and produce as much increase in weight, as when first established.

Scarcity of farm labor in this section is considered by many as another reason for the utilization of land in pasture rather than in cultivated crops. It is apparent that any farm-management program for this section must take into consideration the most efficient utilization of the available pastures. Grass is the major crop. Cattle serve only as a means for its utilization. Because of the relative scarcity of corn and the abundance of grass most of the cattle from this section are marketed as grass-finished beef. The common practice is to market steers for slaughter at 3 to 5 years of age, when their market weight is 1,250 to 1,500 pounds.

EARLY DEVELOPMENT OF THE BEEF-CATTLE INDUSTRY IN VIRGINIA

The beef-cattle industry has long been of considerable importance in the agriculture of Virginia. The State's early colonization, together with favorable climatic and pasture conditions, afforded the setting for the development of one of the leading beef-cattle producing sections in the early history of this country. Improved breeding cattle from England, largely Shorthorns, were imported, and for years Virginia herds supplied a good proportion of the cattle exported from this country. These export cattle were driven or shipped to the seaboard cities, usually Baltimore, New York, or Philadelphia, where they were loaded on ships for English markets. Bluegrass and "shock" corn produced beef that received favorable recognition on the London markets and competed strongly with the local English product.

RISE AND DECLINE OF UNITED STATES EXPORT TRADE IN CATTLE AND BEEF

Prior to 1870 the export trade of the United States in cattle and beef was relatively small. In the late seventies successful methods were developed for shipping fresh meats under refrigeration. At that time cattle production was expanding at a tremendous rate in the States west of the Mississippi River, where new grazing lands were being opened to settlers. From 1870 to shortly after 1900 exports of live cattle and fresh beef increased rapidly, most of this trade being with Great Britain. The peak of cattle exports was reached in 1904, when the year's total amounted to almost 600,000 head. The peak in exports of fresh beef came in 1901, the total volume for that year amounting to more than 354,000,000 pounds, or the equivalent of more than 500,000 steers.

Just prior to the time that the export trade of this country had reached its peak, refrigeration methods had been perfected sufficiently to make it possible to ship dressed beef from South American countries to England. Since South American beef was being produced at a much lower cost than that in the United States, in a short time it was forcing the United States product off the English markets. Exports of both fresh beef and cattle from the United States declined sharply after 1906, whereas those of chilled and frozen beef from Argentina, the chief producing country of South America, rapidly increased.

Coincident with the decrease in our export trade in cattle and beef came a decline in our cattle production and a gradual rise in cattle prices. By 1912, when cattle numbers had reached the low point in this country, our export trade had almost entirely disappeared, whereas Argentina had obtained practically a monopoly of the English market in chilled beef.

During the World War a tremendous demand for beef for the allied armies developed, but abnormal shipping conditions made it rather difficult to transport supplies from South America. For a time, therefore, the United States again dominated the beef-export trade. The recovery was short-lived, however, for, after the war, when shipping conditions had again returned to normal, Argentina not only regained this trade but increased it to the greatest volume in that country's history.

The United States is now practically on a self-sustaining basis so far as beef production and consumption are concerned. More beef and cattle are imported than exported, but the net imports represent only a small percentage of the total beef consumed. The imports consist mostly of stocker and feeder cattle from Canada and Mexico and canned beef from South America.

The export trade in live cattle undoubtedly was an influential factor in developing the type of steers now commonly produced in Virginia. Ocean freight rates were on a head basis. Heavy steers, after the shrink in weight while being transported from pastures to seaboard, lost only a little more on the ocean voyage, and when slaughtered they dressed out firm carcasses of the type demanded by the English trade. An aged feeder steer of the type available would put on a greater increase in weight on grass alone than would a young animal. All these factors were conducive to the production of heavy, finished cattle, weighing up to 1,650 pounds and averaging from 1,350 to 1,550 pounds at home. Such is the kind now commonly raised in the mountain sections of Virginia and in West Virginia.

CHANGES IN THE BEEF-CATTLE INDUSTRY OF THE UNITED STATES

During the last two decades there has been a transition in the beef-cattle industry in the United States which has developed new problems in production and marketing. From a beef surplus producing Nation with a fairly large export trade, this country, about 1912, found itself temporarily on an import basis and its cattle industry at the low point in a production cycle. Numbers on farms at the beginning of 1912 totaled approximately 55,000,000 head, as compared with more than 64,000,000 in 1904. The high prices of beef and feeder cattle that accompanied this reduction in number brought complaints from both consumers and cattle finishers. A little later came the World War with its increased demands and speculative conditions; this hastened the herd expansion that had begun after 1912. When the war ended in 1918 cattle numbers totaled more than 71,000,000 head, an increase of 16,000,000 over the number in 1912. Shortly afterwards came the most marked price deflation in history, and this deflation with the readjustments it enforced made it impossible for many producers, and difficult for all producers, to continue in business. During the four years, 1921–1924, cattle prices were extremely low as compared with production costs. During this period the cattle industry was generally unprofitable, and financial losses were heavy. From 1922 to near the end of 1926 extensive liquidation took place, cattle numbers were greatly reduced, and many producers left the cattle business entirely.

Price improvement developed gradually in 1925 but was not generally perceptible until late in 1926. During the next two years prices advanced rapidly as slaughter supplies decreased. At the beginning of 1928 cattle numbers were almost to the low point reached in 1912 and were 21.8 per cent, or 15,500,000 head, less than the number on hand in 1918. Although numbers have increased about 3,280,000 head during the last three years, the industry at present is generally on a profitable basis, but, in order to maintain this basis and realize maximum returns, producers must give recognition to changes in demand and in production conditions and must adjust production accordingly. The relative changes in cattle numbers, beef production, and cattle prices from 1900 to 1930 are shown graphically in Figure 1.

During the past 25 years of marked changes in cattle numbers and prices some rather rapid developments have taken place in beef-production methods, particularly in the Corn Belt, where corn is the important feed for finishing cattle for market. In the early part of this period slaughter supplies included a much larger proportion of grass cattle than they have in more recent years. Cattle feeders who followed the practice of intensive feeding with corn usually fed aged steers which were marketed at rather heavy weights. During much of the time beef was relatively low in value, and consumers were accustomed to buying heavy cuts. The so-called "baby beef" (finished yearlings) was more or less a curiosity on the market.

During more recent years cattle feeding in the Corn Belt has passed largely into the hands of experienced feeders—men who are specialists

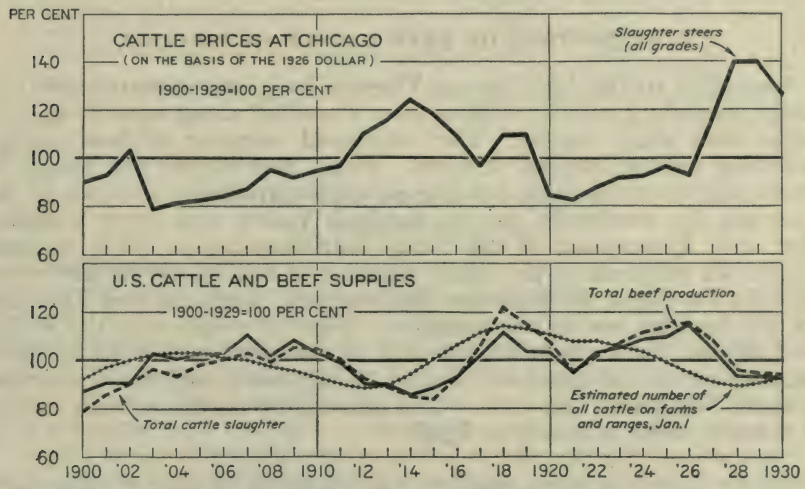

FIGURE 1.—CATTLE NUMBERS, SLAUGHTER, BEEF PRODUCTION, AND PRICES, 1900–1930. EACH SERIES EXPRESSED AS A PERCENTAGE OF ITS AVERAGE FOR 1900–1929

A comparison of the price and production curves shows how the low level of prices from 1919 to 1926 discouraged cattle production; marketings and slaughter exceeded calf crops, and numbers remaining on farms and ranges rapidly declined to the lowest point since 1912. In 1927 and 1928 the production in numbers on farms was reflected by a curtailment in market and slaughter supplies and sharply advancing prices. A similar situation prevailed in the previous production cycle. Increased slaughterings from 1905 to 1911 were followed by a considerable reduction in market supplies and advancing prices before herds were materially increased. The price decline in 1930 was a reflection of reduced consumer demand due to the business depression

in a business that requires considerable skill and judgment. At the same time domestic demand has centered more on grain-finished beef, and particularly on beef that possesses a high degree of tenderness and can be purchased in small cuts without excess waste fat. Beef of this character is usually obtained from early-maturing types of cattle, those producing lightweight carcasses. By shifting to younger and lighter weight cattle the producer and the feeder are not only able to furnish a more desirable product but are often able to make larger profits on their operations.

Beef from heavy, mature cattle that have been well finished now finds its chief outlet in the kosher markets and in the high-class hotel and restaurant trade. The outlet is relatively limited, however, and there is little demand for the lower grades of heavy beef. It is apparent, therefore, that the market for heavy beef can be easily over-

supplied. When this occurs such beef must be offered at reduced prices in order to move it into consumptive channels. Because of consumers' preference for beef from finished grain-fed cattle of the lighter weights, it is becoming more difficult to sell heavy, mature, grass-finished steers on a parity with lighter steers of the same grade, and this fact has created some perplexing problems for Virginia cattle producers.

If the present level of cattle prices eventually results in increased cattle production, as seems likely, lower prices may be expected to follow, and then still greater discrimination will be shown by consumers in making beef purchases. The producer who endeavors to anticipate consumer preferences and is able to readjust his methods so as to produce what is wanted at the lowest cost will be in the best position to continue in the cattle business.

DISTRIBUTION OF BEEF CATTLE IN VIRGINIA

According to the 1925 census Virginia had approximately 680,000 cattle, excluding calves. These were classified about equally as beef cattle and dairy cattle. The estimated number of beef cattle, including calves, totaled 420,000. Some beef cattle are raised in practically every county, but the principal producing sections of the State are the southwest, the Shenandoah Valley, and north Virginia. (Fig. 2.) Twenty-six of the thirty-four counties in these sections contain 72 per cent of the entire number of beef cattle in the State. Russell, Tazewell, Washington, Rockingham, Augusta, and Fauquier are the leading beef-cattle counties. The 17 counties in the southwest section have about 41 per cent of the total in the State, the 8 counties in the Shenandoah Valley 20 per cent, and the 9 counties in north Virginia 17 per cent. The number by classes in each county in these sections is shown in Table 1.

TABLE 1.—*Number of steers, beef cows, and heifers and all cattle on farms in the three principal beef-producing sections of Virginia, January 1, 1925*

Section and county	Steers	Beef cows	Beef heifers	All cattle
North Virginia:	*Number*	*Number*	*Number*	*Number*
Culpeper	2,554	2,999	569	12,724
Fairfax	191	335	123	11,636
Fauquier	10,031	3,341	688	25,618
Greene	909	621	398	5,172
Loudoun	8,432	2,751	733	25,609
Madison	1,941	5,253	687	10,516
Orange	1,198	2,386	469	9,762
Prince William	1,684	1,477	270	9,313
Rappahannock	5,217	787	668	10,628
Total	32,157	19,950	4,605	120,978
Shenandoah Valley:				
Augusta	8,421	7,442	2,760	33,941
Clarke	1,593	2,640	481	6,625
Frederick	816	2,181	501	9,233
Page	1,753	2,079	576	6,365
Rockbridge	3,180	2,742	1,360	15,176
Rockingham	10,470	7,214	3,064	32,830
Shenandoah	2,667	2,146	810	13,295
Warren	1,520	764	371	5,206
Total	30,420	27,208	9,923	122,671

TABLE 1.—*Number of steers, beef cows, and heifers and all cattle on farms in the three principal beef-producing sections of Virginia, January 1, 1925*—Continued

Section and county	Steers	Beef cows	Beef heifers	All cattle
Southwest Virginia:	*Number*	*Number*	*Number*	*Number*
Bland	2,399	2,311	796	7,826
Buchanan	191	955	389	7,200
Carroll	2,436	2,465	1,349	14,253
Dickinson	192	1,164	457	5,625
Floyd	3,248	2,825	1,747	15,105
Giles	2,616	1,701	904	8,967
Grayson	4,536	5,242	2,527	20,438
Lee	5,086	4,042	2,121	18,288
Montgomery	5,908	2,269	921	16,015
Pulaski	4,454	2,000	949	10,859
Russell	10,804	3,425	1,439	22,232
Scott	3,221	4,225	2,058	18,462
Smyth	2,779	1,483	1,202	9,883
Tazewell	9,851	4,043	1,267	19,436
Washington	8,326	4,369	2,502	25,610
Wythe	5,004	2,024	1,831	15,803
Wise	654	372	189	6,927
Total	71,705	44,915	22,648	242,934
Total of three sections	134,282	92,073	37,176	486,583

Figures from Bureau of the Census.

METHODS OF FINISHING STEERS

SOUTHWEST VIRGINIA

In southwest Virginia the production of beef cattle is one of the major agricultural enterprises; about 2,500 carloads of cattle are usually shipped out of that section each year. Most of these cattle are fattened on grass, the usual practice being to carry cattle through the winter on a maintenance ration and fatten for market on bluegrass pasture during the summer. In certain parts of this section the land does not seem well adapted to bluegrass, and the practice there is to produce stocker and feeder cattle, which are usually finished for market in those counties in which grazing and feed conditions are more favorable. The near-by mountain sections in Tennessee, North Carolina, and West Virginia are also sources of feeder steers for the finishers in this section. In many instances these feeder steers are the progeny of cows kept by small farmers for milking purposes. These cows usually show more beef breeding than dairy breeding, being commonly of the red Shorthorn, dual-purpose type. When purchased as feeders for finishing for market the steers usually are from 2 to 4 years of age, mostly 3-year-olds.

Feeder steers are usually obtained in early October and are pastured until about December 1. The length of this fall-grazing period depends on weather conditions and the quantity of grass available. Most operators begin winter feeding only when it is evident that steers are losing weight on grass. If seasonal conditions are favorable, a light ration consisting principally of shock corn and hay is fed, and the steers are kept on pasture until the end of January. In some instances steers are pastured throughout the winter.

A few steers are fed in small feed lots during the winter, but ordinarily they have the run of small pasture lots, or fields, from 5 to 20 acres in size. The most common practice in winter feeding is to feed from 15 to 25 bushels of corn in the shock with some hay and straw. To a more limited extent silage is used in the winter-feed ration. A more detailed discussion of feeding practices appears in

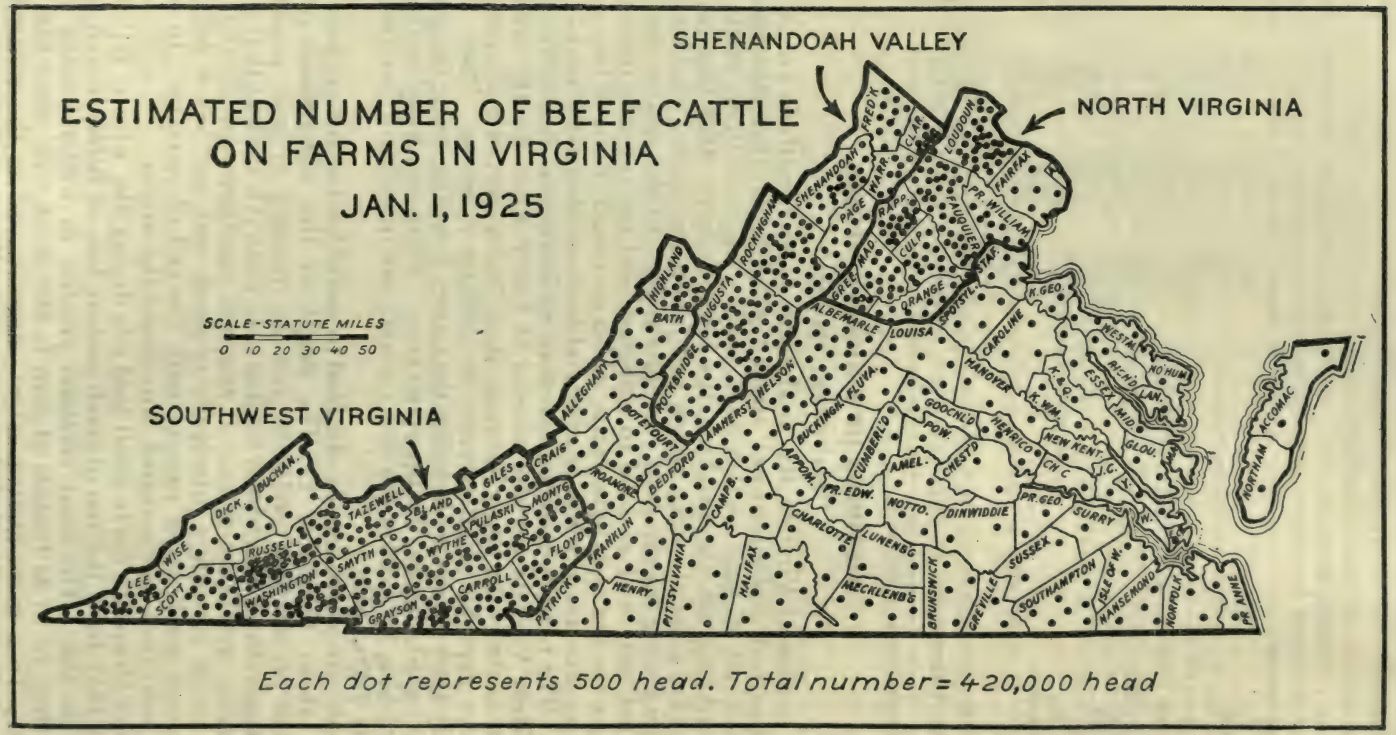

FIGURE 2.—The southwest, the Shenandoah Valley, and north Virginia are the principal beef-producing sections of Virginia. The southwestern section alone has about 41 per cent of the entire number of beef cattle in the State, the Shenandoah Valley has 20 per cent, and north Virginia has 17 per cent

that section of this bulletin that summarizes the results of feeding operations on selected farms of which records were obtained.

Regardless of the method of wintering, the usual practice on all farms is to turn steers on grass about April 20 to May 1, and to finish on grass without additional feed during the pasture season. The grazing season in southwest Virginia ordinarily extends from about April 15 to about December 1, although on some farms pastures are grazed practically throughout the year. Cattlemen in that section as a rule expect to dispose of their grass-finished steers at any time from the latter part of July to early November, depending on grazing and marketing conditions.

SHENANDOAH VALLEY AND NORTH VIRGINIA

In the Shenandoah Valley and in north Virginia the beef-cattle enterprise is much less important than in southwest Virginia. Steers are fattened or fed on only a small percentage of the farms. Most of the farmers depend on a diversified agriculture for their income. Dairy, poultry, or hog production is highly developed on some farms, and income from fruit, truck crops, and wheat is important, especially in some localities.

In the Shenandoah Valley and in north Virginia the more common practice is to fatten cattle for market after the grazing season by feeding shock corn, cottonseed meal or other concentrates, and silage and roughage, for a period of 75 to 110 days. When ready for market the steers carry about the same degree of finish as the so-called "short-fed" or "warmed-up" steers that are marketed in the Corn Belt. The feeding is done in small feed lots, and the steers are marketed from early December to late March.

The finisher may graze the steers through the summer on his own pasture prior to feeding concentrates, or he may purchase them as feeders in the fall just prior to the beginning of feeding operations. Cattle fattened in this section are usually purchased as feeders in the near-by mountain counties of Virginia and West Virginia, although some are obtained from southwest Virginia and western North Carolina.

METHODS OF SELLING CATTLE

Although some of the larger graziers in Virginia ship their cattle to market and there are a few cooperative-shipping associations in the State, the practice among most cattlemen is to sell livestock at home to local buyers who ship to market, or to a representative of a packer located in one of the eastern cities, such as Washington, Baltimore, Philadelphia, New York, or Boston. This packer representative may be a visiting buyer, or he may be a local man who buys on a commission basis, usually about $1 per head. The volume of direct buying varies considerably from year to year, depending largely on supply and demand conditions in the cattle market. If cattle are scarce and the trend of prices is likely to be upward, slaughterers are generally active buyers in the country. On the other hand, if the supply is abundant and the trend of prices is uncertain or likely to be downward they prefer to buy their cattle on the public markets as needed.

The local buyer, whether representing a packer or buying for his own account, is often a large landowner engaged extensively in pro-

ducing or feeding cattle. One or more buyers operating on a large scale are usually located at each county seat. A survey made in 1922 developed that most of the local buyers had had from 15 to 30 years of experience in buying livestock and that much of their success was due to the personal contacts maintained with the producers with whom they had dealings. An intimate acquaintance with producers enables the buyer to keep informed regarding the type of cattle each is feeding and the methods of feeding. In some instances the buyer employs assistants or "spotters" who keep in touch with the farmers and inform him as to when stock is expected to be ready for market.

Buyers as a rule personally inspect every lot of cattle they contemplate purchasing at least once during the feeding or growing period and note about when the animals will be ready for market. When that time arrives, if a contract has not already been made for the cattle, the purchase price can be agreed upon by personal interview or by telephone. The buyer may not see the cattle at the time of sale, but he almost invariably sees them weighed over the scales. Frequently in 1924 when a contract between the buyer and seller could not be arranged, arrangements were made to ship in the buyer's name, the buyer to receive a nominal agent's commission for the service.

Most of the stock intended to be sent to market or direct to a packing plant is purchased by weight, but it is not uncommon to purchase cattle on a head basis. Deliveries are usually made to the nearest available scales. These may be located on the farm of the seller or on that of a neighbor, or they may be located at a mill or store, or at the railroad loading pens. If weighing fees are assessed they are paid by the seller; they may range up to 25 cents per draft or to 2 cents per 100 pounds of live weight.

Shipping days are determined by the time required to reach the market to which shipments are to be made, since all the markets patronized are largely either 1, 2, or 3 day a week markets; that is, trading is carried on most extensively on one, two, or three days each week. The general practice is to time shipments so as to have them reach destination from 24 to 36 hours before the cattle are to be sold, to give the animals ample opportunity to eat and drink freely and thus take on a big fill.

Shipments consigned from southwest Virginia to Jersey City are usually unloaded for feed, water, and rest at Hagerstown, Md., in compliance with the Federal 28-hour law.

BUYING FOR FUTURE DELIVERY, OR CONTRACT BUYING

Contracting for livestock for future delivery has long been a rather common practice with both local and packer buyers who operate in the southern Appalachian and the bluegrass sections of the South. As far as can be ascertained this custom dates back to the Civil War period, and probably further. In the early days when transportation and news-disseminating facilities were exceedingly slow and imperfect, buyers traveled about the country on horseback and to a large extent were the chief sources of market information for producers.

In order that the producer might be assured of an outlet for his cattle when they were ready for sale and that the buyer might get a sufficient volume of business to justify him in making preparations for a trip to market, both found it advantageous to make contracts

in advance of delivery, usually four to six months. As the buyer assumed considerable risk and expense he found it necessary to buy on a rather wide margin. Furthermore, since he was better informed than the producer regarding market values he naturally used his knowledge to his own advantage as far as possible. Later, as transportation and news-disseminating facilities improved and producers became better informed, the buyers' margins were reduced.

During recent years contracts for grass-fed cattle have been made from February to September for delivery at the end of the grazing season, August to November, and contracts for grain-fed cattle have been made from November to March for delivery from January to April. Frequently, contracts for finished cattle are made as soon as the feeder cattle are placed in the feed lots. This enables the farmer or feeder to calculate in advance approximately what he will receive for his feed and labor, since he avoids all risks of shipping and of market fluctuations.

FURNISHING STOCKERS AND FEEDERS ON CONTRACT

Many buyers furnish stocker and feeder cattle on contract. This practice consists in selling cattle suitable for grazing or feeding to the farmer or feeder with a verbal or written agreement to repurchase them by a certain specified date at a specified margin above the initial price per pound. Prior to the World War this margin usually was 1 to 1½ cents; it was increased to 2½ cents during the war and postwar period of high prices because of the increased cost of feed and labor. Later, the margin was reduced to 2 cents, and in more recent years to 1 and 1½ cents. Little difference is made with regard to quality of the cattle when contracting for feeding. Ownership of the cattle during the feeding period is with the farmer. He pays the taxes and stands all losses. In furnishing cattle to the farmer for feeding it is to the local dealer's interest to price them low in order to reduce the cost to him of the increased weight which the animals will take on. A low purchase price is an advantage to the farmer in the event of the loss of an animal.

As an example, assume that a dealer sells a steer weighing 1,100 pounds to a farmer at 6 cents per pound and agrees to buy the finished animal back at 7 cents a pound. An increase in weight of 300 pounds will cost the dealer $21 plus $11 on the original weight, making a total of $32. On the other hand if he sells the steer for 7 cents per pound and buys it back for 8 cents the additional weight will cost him $24 plus $11 on the original weight, or $3 more than under the other agreement.

Under the contract system of buying feeders the farmer endeavors to obtain 2-year-old and 3-year-old steers with large frame and big bone. Such steers usually consume the maximum quantity of feed and roughage and take on a large increase in weight. Calves and yearlings are seldom, if ever, contracted for future delivery.

PRICE DETERMINATION UNDER THE CONTRACT SYSTEM

In determining the price at which to make contracts for future delivery, the local buyer is influenced by his previous experience, by local competition and general business conditions, by information and advice obtained from his commission firm, and to a large extent by the trend of prices at the time the contracts are made.

Competition is very keen among local buyers in many communities. To maintain a satisfactory volume the buyer must work his territory faithfully and keep in close touch with producers lest competitors take business away from him. The most effective way for him to get business and control it is to supply the producers with their stockers and feeders and make an agreement or contract to buy them back when ready for market. The first few trades made usually establish the general price that is paid throughout the entire section during the season.

The local buyer, accustomed to dealing with many different persons, is generally a better bargainer than the producer. He knows the general ability of each farmer to handle and finish cattle and furnishes each with the grades that he thinks can be handled best. The producer with the best reputation as a farmer and feeder gets the best grades of animals to fatten, whereas the farmer of lesser ability is furnished animals of the lower grades.

In bargaining with the buyer the average producer depends almost wholly on such local information as he can get and what he sees in the newspapers as to the current market prices of cattle. The development of radio in broadcasting market information and the educational work being done by State and Federal agencies in marketing and grade standardization is making it easier for the producer to ascertain values, but until he comes in more direct contact with central markets and gives more attention to the study of trade and consumer demands he will continue to be under great disadvantage in his dealings with the buyer.

DISADVANTAGES OF THE CONTRACT SYSTEM

The general attitude of the cattle raisers apparently is to favor contracting. As a class they are rather conservative, and having had little or no experience in shipping to market, they are generally unwilling to assume the risks involved; hence they prefer to sell at home. It is largely because of this attitude that cooperative shipping has never developed extensively in Virginia and that the local buyer has been able to remain in business. Undoubtedly it has tended to keep the contract system in existence.

During the years when cattle prices were low and showed little tendency to advance, most of the buyers who had incurred heavy losses in the deflation period probably would have been in favor of discontinuing the practice entirely, but they felt they had to continue it or their competitors would get the business. Buyers who made contracts at the beginning of the rise in cattle prices in 1927 reaped large profits, and this stimulated contracting in 1928, but profits in the latter year were considerably reduced because the seasonal downturn in prices came earlier than usual.

One disadvantage of the contract system is that it tends to discourage the production of the better grades of cattle. Practically no recognition is given to grade in making contracts for feeding, as the cattle are all fed on practically the same margin. The buyer, in many cases, determines the type of cattle fed, and as the lower grades cost less than the better grades they tend to reduce his risks. At the same time they require less capital for a given number of animals handled. Another criticism that can be made against the practice of contracting, as it is followed, is that it tends to remove the incentive for producers to keep informed as to changes in market demand and to adjust production accordingly.

MARKET OUTLETS

Four public markets are patronized by Virginia livestock shippers: They are located in Richmond, Baltimore, Lancaster, and Jersey City. Public stockyards are located in Philadelphia and in Washington, but little trading is carried on at either of them. They serve principally as receiving yards for livestock billed to slaughterers who operate in those cities. Shippers in southwest Virginia patronize the Jersey City and Lancaster markets most extensively. Those in northern Virginia ship a considerable portion of their stock to Baltimore. This choice of markets is governed largely by the available railroad service, although the character of the demand at these markets is given consideration. The importance of railroads in the choice of markets is discussed elsewhere in this bulletin.

TABLE 2.—*Monthly receipts of cattle at Richmond, Baltimore, Lancaster, and Jersey City, 1925–1929*

RICHMOND

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1925	2,452	1,264	2,962	2,374	1,937	1,457	1,592	2,627	3,072	3,180	2,910	1,956	27,783
1926	2,237	1,831	1,426	1,040	937	1,247	1,543	1,481	1,921	4,281	2,147	1,935	22,026
1927	2,008	1,744	1,516	1,371	880	540	1,857	1,481	1,825	3,073	1,594	2,053	19,942
1928	1,611	1,799	1,554	910	496	902	1,115	1,547	2,601	1,998	1,659	1,166	17,358
1929	870	975	1,120	1,152	772	944	1,190	1,343	2,091	2,662	1,645	856	15,620
Average	1,836	1,523	1,716	1,369	1,004	1,018	1,459	1,696	2,302	3,039	1,991	1,593	20,546

BALTIMORE

1925	11,869	10,045	11,524	9,599	8,929	7,853	14,677	18,925	22,470	22,628	13,573	11,075	163,167
1926	13,165	8,666	9,400	8,614	10,021	9,560	12,301	11,937	23,015	21,765	14,032	14,890	157,366
1927	13,599	10,087	11,295	11,895	10,329	10,948	15,234	16,462	20,655	19,542	13,386	13,236	166,668
1928	11,405	10,032	10,918	9,112	8,354	7,634	8,407	13,175	18,682	17,153	15,900	11,469	142,241
1929	12,416	9,217	9,663	8,487	8,242	8,220	10,536	13,429	15,586	17,756	11,601	11,711	136,864
Average	12,491	9,609	10,560	9,541	9,175	8,843	12,231	14,786	20,082	19,769	13,698	12,476	153,261

LANCASTER

1925	9,880	4,908	6,061	5,399	7,562	12,812	19,116	35,602	25,644	41,986	29,608	12,694	211,272
1926	10,403	7,550	7,400	6,260	8,415	9,959	17,296	19,357	31,361	43,053	27,868	14,679	203,601
1927	9,922	6,517	7,079	7,654	9,247	11,087	16,154	24,446	31,181	35,453	24,385	12,011	195,136
1928	9,347	7,457	6,815	6,927	9,559	15,971	18,545	25,925	38,262	29,470	22,266	12,774	203,318
1929	7,946	6,138	7,750	8,357	8,857	12,767	18,220	22,340	24,938	30,605	20,474	11,682	180,074
Average	9,500	6,514	7,021	6,919	8,728	12,519	17,866	25,534	30,277	36,113	24,920	12,768	198,680

JERSEY CITY

1925	24,399	18,130	15,374	19,471	16,082	14,586	14,782	21,888	19,116	22,885	14,321	18,970	220,004
1926	14,607	16,870	14,775	16,597	19,318	15,079	12,336	16,694	15,731	17,997	15,293	14,581	189,878
1927	13,878	15,477	12,597	13,724	16,660	11,987	12,774	18,814	19,185	23,742	15,589	14,813	189,240
1928	19,495	15,681	14,814	15,931	20,749	17,780	19,731	17,413	21,050	24,908	19,630	17,837	225,019
1929	23,939	16,493	17,379	22,276	17,401	15,955	20,252	15,534	20,305	22,569	16,886	18,443	227,432
Average	19,264	16,530	14,988	17,600	18,042	15,077	15,975	18,069	19,077	22,420	16,344	16,929	210,315

Monthly receipts of cattle, excluding calves, at these four markets during the five years, 1925–1929, are shown in Table 2. The figures include all cattle unloaded, whether offered for sale, billed direct to packers, or unloaded for feed and water. The shipments direct to packers are an important item in the total receipts at Baltimore and

at Jersey City, being approximately 31 and 68 per cent, respectively, of the totals at these markets during the three years 1922–1924. Cattle received for sale comprised 32 per cent of the total receipts at Jersey City and slightly more than 50 per cent of those at Baltimore during this period. The proportion of cattle for sale is greatest from August to December, approximately one-half of the October receipts at Jersey City comprising shipments for sale.

RICHMOND

The Richmond market is limited as to the number of cattle that can be absorbed by local slaughterers; hence relatively few shipments from southwest Virginia are sent there. Most of the shipments consigned to that market comprise cows and heifers, with a few low-grade steers. The demand for stockers and feeders at Richmond is small, as that market is not adjacent to any well-developed feeding district where large numbers of cattle are finished on concentrates.

BALTIMORE

Baltimore is the principal market for most of the shippers in north Virginia and the Shenandoah Valley. Monday is the most important market day at Baltimore, although considerable trading is done in cattle on Saturdays when a good supply of heavy cattle is available. Many out-of-town slaughterers visit the Baltimore market on Saturday to make purchases for slaughtering the following week if receipts of desirable cattle are sufficiently ample to justify making the trip. Many Virginia shippers prefer to ship their low-grade and lightweight steers to Baltimore because they think it offers a better outlet for such stock than some of the other markets. It also seems to hold favor as a market for cows and heifers; many such cattle come from near-by dairy herds. Stocker and feeder shipments from that market are insignificant, averaging slightly more than 2 per cent of the annual receipts.

LANCASTER

Lancaster's importance as a market for Virginia shippers is due to the fact that it is an outlet for lightweight and unfinished steers, more suitable for feeding than for slaughtering. This market is located in what is known as the Lancaster feeding district, which comprises 16 counties in Pennsylvania and 2 counties in Maryland. The latter are Cecil and Harford. The Pennsylvania counties are Adams, Berks, Bucks, Chester, Cumberland, Dauphin, Delaware, Franklin, Juniata, Lancaster, Lebanon, Lehigh, Montgomery, Perry, Schuylkill, and York. The Pennsylvania Bureau of Markets estimates that the number of cattle fed in this district annually has ranged from 98,000 in 1923 to 132,000 in 1928. The number fed each year depends somewhat on feed conditions in the district (that is, the crops raised prior to feeding), on the financial results of the previous year's feeding, and on the condition of the cattle market at the time feeder cattle are purchased. These feeders are bought from the latter part of July to early December. They usually are bought through commission firms or from dealers at Lancaster who specialize in this class of stock.

A few operators in this district feed from 200 to 600 steers each year, but the majority keep only a few head, the chief objects in feeding being to obtain manure for tobacco fields and to utilize feed,

produced on the farms, which could not be readily sold. The 1925 census figures show 11,457 farms in Lancaster County and, according to the Pennsylvania Bureau of Markets, cattle are fed on about 5,700 of these farms; the average number fed per farm is about 7 head.

There is a great variation among feeders as to the kind of feeder cattle wanted. Some use rather low-grade steers provided they can be bought relatively cheap. Others prefer steers with more finish and quality, even though the cost per pound is considerably greater. As a rule, however, the majority preference is for steers of big bone and big frame, that will consume the maximum quantity of feed and make the greatest increase in weight, the objective being to turn out a fed steer weighing from 1,400 to 1,500 pounds which can be marketed from April to June, inclusive.

Many of the feeder cattle on the Lancaster market are received from Canada and western markets, the St. Paul market being the heaviest of these contributors, with the markets at Chicago, East St. Louis, and Kansas City next in order. Canadian cattle are preferred by many feeders, but the imposition of a tariff of 1½ and 2 cents per pound in 1922 and which was further increased in 1930 has tended to curtail their importations. But cattle from the southern Appalachian sections appear to be gaining in popularity, judging by the increase in receipts from those sections during recent years. This increase is due in part to the danger of loss from hemorrhagic septicemia, or what is commonly called "shipping fever" in shipments from distant markets. Many feeders in the Lancaster district are of the opinion that if Virginia shippers would send better grades of stockers and feeders to the Lancaster market there would be an increased demand there for Virginia cattle.

TABLE 3.—*Car-lot receipts of cattle at Lancaster stockyards, by State or market of origin, 1922–1929*

State or market of origin	1922	1923	1924	1925	1926	1927	1928	1929
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
Virginia	1,474	1,365	1,802	1,733	1,697	1,144	1,192	1,218
West Virginia	295	267	309	398	425	243	300	243
Kentucky	86	125	332	60	32	49	49	50
Tennessee	336	262	394	292	146	123	147	127
North Carolina	58	42	63	56	19	13	16	8
Maryland	53	60	47	39	42	33	87	125
Pennsylvania	971	1,166	765	678	676	538	478	223
New York	67	54	74	68	58	71	65	63
Ohio	44	78	63	47	50	60	21	25
Indiana	31	50	62	48	56	30	20	12
Michigan	50	12	8	14	10	2	15	43
Iowa			27	140	56	28	15	11
Texas			29	4	14	14	8	19
Other States		75	23	15	10	56	61	25
St. Paul	1,341	983	988	1,259	1,193	807	802	800
Chicago	962	732	643	759	659	1,035	889	656
East St. Louis	851	352	470	459	288	226	246	190
Kansas City	222	205	166	121	129	160	79	41
Omaha	38	46	6	26	11	9	3	7
Buffalo	142	93	46	69	25	54	104	34
Pittsburgh	97	129	110	32	40	10	30	68
Canada	175	190	162	266	341	1,023	854	663
Total	7,293	6,286	6,589	6,583	5,977	5,728	5,481	4,651

Reports of Pennsylvania Bureau of Markets.

Table 3 shows the State or market origins of all cattle received at Lancaster during the eight years, 1922–1929, as reported by the Pennsylvania Bureau of Markets. Virginia contributed 1,337 cars in 1919, 1,261 cars in 1920, and 1,410 cars in 1921. Of the total of 1,218 cars received from Virginia in 1929, 1,075, or 88 per cent, arrived during the second half of the year. In 1923, receipts from Virginia in the last six months numbered 1,275 cars out of a total of 1,365 for the year, and in 1924, 93 per cent of the total was received in the second six months.

Cattle fed in the Lancaster district are returned to market as fat cattle during the spring and early summer, or during the period when practically no cattle from Virginia are on the market. The majority are first offered for sale on the Lancaster market, although many are shipped to Jersey City and to Baltimore and direct to packers in Philadelphia, Boston, and smaller eastern cities.

JERSEY CITY

Jersey City is the gateway to New York City, and practically all stock received there is slaughtered in the New York metropolitan district, which includes not only greater New York but the near-by cities in New Jersey. Mondays, Wednesdays, and Fridays are the important market days. There is no stocker and feeder outlet at this market, nor is there any other market to which stock can be reconsigned from Jersey City for sale. Virginia shippers as a rule send only their heavy and best-grade steers to Jersey City, as practically all cattle slaughtered in the New York district are koshered and the kosher trade prefers heavy cattle. The importance of the kosher trade in the marketing of Virginia cattle is discussed elsewhere.

Table 4 shows the car receipts of cattle offered for sale at Jersey City during the six years 1922–1927, inclusive, and the number of head received for sale in 1929, grouped according to State origins. The receipts in 1928 were omitted from the table because during part of the year the records were kept by cars, whereas during the remainder of the year they were kept on a head basis. Receipts from Virginia and West Virginia are shown separately, although cattle from these States are similar in general quality. They are produced under almost the same conditions and are marketed in the same season of the year. In considering the composition of the receipts at Jersey City and the relative competition of the different groups of States, Virginia and West Virginia should be grouped together. During the six years 1922–1927 these two States contributed about 43 per cent of the carload shipments of cattle offered for sale at Jersey City. In 1929 they supplied about 35 per cent of the total number of head offered for sale. Receipts from these States fell off sharply after 1925.

Cattle from Kentucky and Tennessee are generally thought by the trade at Jersey City and New York to average somewhat higher in grade than those from the two Virginias, primarily because they are supposed to have been fed more grain. Receipts from these two States are grouped together since they offer about the same kind of competition to cattle from the two Virginias. On the average they represent about 4 per cent of the total receipts for sale.

TABLE 4.—*State origins of cattle received at Jersey City for sale, 1922–1927, and 1929*

State or country of origin	Car-lot receipts								Cattle received 1929
	1922	1923	1924	1925	1926	1927	1922–1927		
							Average	Per cent	
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*		*No.*
Virginia	1,066	1,126	910	1,245	587	797	955	29.4	14,509
West Virginia	641	429	367	530	269	336	429	13.2	5,880
Kentucky, Tennessee	170	77	125	137	116	154	130	4.0	2,393
Pennsylvania, Maryland	476	539	530	574	309	334	460	14.1	3,737
New York, New Jersey, Delaware, Connecticut, Vermont	782	961	876	711	827	1,114	879	27.0	29,619
Illinois, Indiana, Iowa, Missouri, Nebraska, Ohio, Minnesota, Michigan, Kansas	716	428	290	350	285	159	371	11.4	2,522
North Carolina, South Carolina, Alabama, Georgia	19	6	1	4	4	13	8	.2	245
Colorado, Texas, Oklahoma, New Mexico	80	36	0	1	2	0	20	.6	0
Canada	0	0	3	2	0	13	3	.1	56
Total	3,950	3,602	3,102	3,554	2,399	2,920	3,255	100.0	58,961

Receipts from Maryland and Pennsylvania include dairy cows no longer useful for milking and steers that were fed in the Lancaster feeding district. The latter are marketed during the first half of the year, or when few cattle are being received from Virginia and West Virginia. They therefore offer no competition to Virginia grass cattle. Supplies from Maryland and Pennsylvania also showed a sharp reduction after 1925. During the six years 1922–1927 they comprised 14 per cent of the total receipts for sale. In 1929 they represented less than 7 per cent of the total.

Cattle from New York, New Jersey, Delaware, and the New England States comprise mostly cows and bulls from dairy herds. These dairy cattle yield beef of such low grade that they offer but little competition to Virginia cattle. New York furnishes the bulk of the supply, and the total has been increasing in recent years, thus reflecting the growth of the dairy industry.

The receipts of cattle for sale from the Corn Belt or Middle Western States are rather evenly distributed throughout the year. It is believed that as a rule they represent mostly consignments from speculators and traders at mid-western markets who occasionally like to try out the Jersey City market. These receipts from the Corn Belt States furnish the chief competition to cattle from Virginia and West Virginia.

The few cattle received from the Carolinas and other Southern States can not be considered seriously as competitors of Virginia cattle. The same can be said of the small number of shipments received from Texas, Oklahoma, Colorado, and Canada.

TRANSPORTATION SERVICE AS A FACTOR IN MARKET SELECTION

The railroad facilities available to a livestock shipper are usually the most important factor in determining his choice of a market. The railroad that serves him usually provides a service and tariffs that are more favorable to the markets located on its line, or the lines

with which it makes direct connections, than it does to those markets located on competing roads. For instance, southwest Virginia livestock shippers are served by the Norfolk & Western Railway, and its tariffs, train schedules, and reconsigning privileges for shipments originating on it are more favorable for those routed via Hagerstown, Md., where connections are made with the Pennsylvania Railroad to Lancaster and Jersey City, than for those routed via other points. When a shipper on the Norfolk & Western does not care to avail himself of the reconsigning privileges he may find it equally advantagous to ship to Baltimore. Shipments originating on some of the other railroads in Virginia, particularly those serving north Virginia, are entitled to reconsigning privileges at Baltimore which are not accorded to shipments originating on the Norfolk & Western and billed to that market. This accounts in part for the fact that north Virginia sends a greater proportion of its shipments to Baltimore than does the southwest section.

Under the reconsigning privilege livestock may be shipped to a market, and if the offered price is unsatisfactory the stock can be reconsigned to another market for an extra cost, amounting to the differential over the rate to the first market plus a reconsigning charge of $2.70 a car. At Baltimore there is also a housing charge of $3 a car.

If the freight rate from a given loading point to Baltimore is 50 cents per 100 pounds and 53 cents to Jersey City and the shipment is entitled to the reconsigning privilege, the additional cost for reshipping from Baltimore to Jersey City would be 3 cents per 100 pounds plus $5.70 per car. If the shipment is not entitled to the reconsigning privilege the cost of reshipping from Baltimore to Jersey City is 28.5 cents per 100 pounds.

Shipments originating on the Norfolk & Western railroad and billed to Baltimore via the Pennsylvania or the Western Maryland Railway can not be reconsigned to Philadelphia, Lancaster, or Jersey City, as there are no through rates on these roads to these points via Baltimore. From Norfolk & Western stations to Baltimore via the Baltimore & Ohio Railroad shipments may be reconsigned to Philadelphia and Jersey City.

Shipments billed to Lancaster can be rebilled to any point in the Lancaster zone (eastern boundary Bristol, Pa., western boundary Harrisburg, Pa., northern boundary New Boston Junction, Pa., and southern boundary Porter, Del.), at an additional charge per car of $2.70 for diversion. It is not even necessary that the animals be reloaded in the same car in which they arrived. This privilege is particularly important to shippers of stock which may be suitable for feeding, for it applies to what is known as the Lancaster feeding district and enables feeder buyers in that district to move cattle that they have bought on the Lancaster market to feed yards at a small cost.

Shipments reconsigned from Lancaster to Jersey City would carry the diversion charge of $2.70 per car plus a rate differential of 2 to 4 cents per 100 pounds. Shipments reconsigned to Pennsylvania points outside the Lancaster district are subject to the diversion charge of $2.70 per car plus a freight charge varying from $19 to $25 per car.

Shippers find the reconsigning privilege a material advantage, because if the first market proves to be unsatisfactory another can be tried at relatively small additional cost. Furthermore this privilege encourages out-of-town buyers to buy on the Baltimore and Lancaster markets, because they can make use of it in reshipping their purchases to their killing plants or feed yards and effect a saving in freight charges.

MARKET DESTINATIONS OF CATTLE FROM SOUTHWEST VIRGINIA

Records of cattle shipments from southwest Virginia during the three years, 1922–1924, were obtained from the Norfolk & Western Railway which traverses almost the full length of that section and transports practically all of the cattle shipped from it. The bulk of the shipments were from Montgomery, Pulaski, Wythe, Smyth, Washington, Tazewell, and Russell Counties. Table 5 shows the destinations of the shipments, which for the three years numbered about 2,500 cars annually. Greater New York and Philadelphia receive most of the slaughter cattle from this section. Many of the shipments, particularly those to Philadelphia, Boston, and some of the smaller cities, represent shipments direct to slaughterers. A few of the slaughterers in greater New York also at times buy direct from the producers in Virginia. Although the available data will not permit segregating shipments of slaughter cattle from those going to feed lots it appears that from 45 to 60 per cent of the total shipments are sent to slaughter markets and the remainder to various feeding points. The bulk of the latter pass through the Lancaster stockyards. Most of the shipments listed as "miscellaneous" in Pennsylvania were probably first received at Lancaster, as in most instances they represented cattle rebilled to final destinations in the Lancaster feeding district after being sold on that market. About 8 per cent of the total shipments were cattle moving to local points in Virginia for feeding or grazing. The proportion of cattle going to feeder markets during 1923 and 1924, especially the latter year, was much greater than in 1922 and in 1925. This was largely because of the unfavorable price conditions for slaughter cattle during the summer and early fall of 1924.

TABLE 5.—*Destination of cattle shipped from southwest Virginia over the Norfolk & Western Railway, 1922–1924*

Destination	1922	1923	1924	Destination	1922	1923	1924
	Cars	*Cars*	*Cars*		*Cars*	*Cars*	*Cars*
Greater New York	957	852	513	Providence, R. I.		8	
Lancaster, Pa.	631	422	982	Camden, N. J.			7
Philadelphia, Pa.	397	194	268	District of Columbia	2	3	
Richmond, Va.	60	72	104	Other points in—			
Baltimore, Md.	23	21	76	Pennsylvania	169	351	188
Reading, Pa.	22	41	25	Virginia	185	194	189
Boston, Mass.	10	37	17	Maryland	14	12	6
Wilmington, Del.	9	19	22	North Carolina	15	15	15
Alexandria, Va.	27	15	7	Tennessee	17	22	20
Frederick, Md.	11	8	5	Other States	13	11	24
Bridgeport, Conn.	6	11	1				
Chester, Pa.	7	7	3	Total	2,575	2,315	2,472

SEASONAL MOVEMENTS OF VIRGINIA CATTLE

The bulk of the Virginia cattle marketed move to market during a comparatively short period each year. The time of this movement and the relative competition which Virginia cattle meet with other producing sections which ship to Jersey City is shown in Figure 3. In this chart it is well to consider the receipts from Virginia with those from West Virginia because of the similarity of conditions under which they are produced and marketed. The chart represents a total of 3,115 cars of cattle, being the average yearly number received for sale at Jersey City during the five years 1923–1927. The Virginia shipments totaled 933 cars or 30 per cent of the yearly average and those from West Virginia 386 cars, or 12.4 per cent. The two States

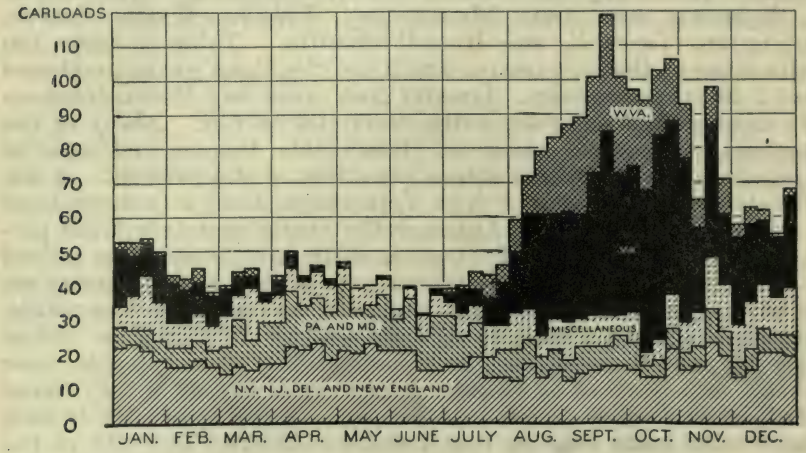

FIGURE 3.—CATTLE RECEIVED FOR SALE AT JERSEY CITY, BY STATE OF ORIGIN, 1923–1927

Virginia contributes 30 per cent of the cattle received at Jersey City for sale and West Virginia 12.4 per cent. Approximately 86 per cent of the yearly shipments of cattle from southwest Virginia move to market from the middle of August to the latter part of November, and these make up a large part of the market supply at Jersey City during this period

combined contributed 42.3 per cent of the average total. Thirteen per cent of the receipts from Virginia and 11 per cent from the two States combined arrived during the period from January 1 to April 8. Marketings during this period represent mostly fed cattle from north Virginia, as practically no shipments are received from southwestern Virginia at this time.

Receipts from the two Virginias between the first week in April and July 1 are insignificant, this being an in-between period following the fed-cattle movement in which grass cattle are not yet ready for market. From March 1 to the middle of July, Pennsylvania and Maryland contribute most heavily to the eastern markets. Some of the shipments from these two States consist of old dairy cows and bulls but most of them are steers fattened in the Lancaster feeding district. Shipments from New York, Delaware, Connecticut, and New Jersey are mostly dairy cows and bulls, and their heaviest movement takes place from April to June, inclusive.

A few Virginia grass cattle are sent to market in July, but the market movement of these cattle as a rule does not reach any substantial

volume before the middle of August. Ordinarily the bulk of the shipments move during September and October, and the season ends the latter part of November. The normal marketing period covers four to five months, but it may be hastened or delayed, depending upon pasture and market conditions. Of the two factors, pasture conditions are the most important.

A prolonged rainy season which results in "washy" grass during the summer prevents the cattle from putting on the hard finish that is desired. When such conditions exist producers hold their cattle on pastures as long as possible, and the marketing period is delayed. A dry summer causes the grass to cure early. This hastens the fattening process and results in early marketing. Dry weather that results in a scarcity of grass also forces early marketing. This condition prevailed in 1925, with the result that more than 60 per cent of the shipments from southwest Virginia that year moved during August and September.

The usual practice of the grazier is to hold back his cattle as long as grass is plentiful in order to obtain the best utilization of the grass and the largest gains in weight during the grazing period. Grass is the major crop, and the cattle serve only as a means of converting it into a salable product. As soon as the steers have taken on the maximum amount of flesh that can be obtained from grazing they are ready for market, and the time of marketing can not be delayed materially without taking considerable risk. The finished cattle therefore, are semiperishable and must be marketed regardless of the market situation. Their perishability is increased somewhat by reason of their age. When they have reached maturity it is impracticable to hold them for further development or finishing after the end of the grazing period. With younger cattle, more latitude in the time of marketing is permitted as they can be retained for a longer period on the farm without material loss.

Of all the cattle received annually for sale at Jersey City, about 64 per cent usually arrive during the last six months of the year, and 37 per cent arrive during the 12 weeks following the middle of August. Virginia's contribution during the 6-month period averages 40 per cent and West Virginia's about 33 per cent of all the cattle on sale during that time. During the 12-week period the two States furnish about 70 per cent of all the cattle on sale. Any surplus or glut on the market at this time, therefore, is caused by the heavy shipments from these two States. The fact that market receipts during these 12 weeks are often greater than can be absorbed except at declining prices is one of the chief marketing problems of Virginia shippers and indicates the desirability of lengthening the marketing period.

Southwest Virginia is the largest contributor of cattle for sale at the Jersey City market during the period when grass cattle are marketed. Table 6 shows the number of cars loaded monthly in this section for all destinations during the four years, 1922–1925. An average of 86 per cent of the shipments moved during the four months, August to November, inclusive. It will be noted that there was some variation in the time of shipping. The 1922 and 1925 seasons were earlier than those of 1923 and 1924. Early marketing is to be recommended as a rule because the best prices for the grades of cattle produced in that section usually prevail during the early

summer. Cattle marketed late are forced into competition with the hordes of grass cattle which move to market from all sections of

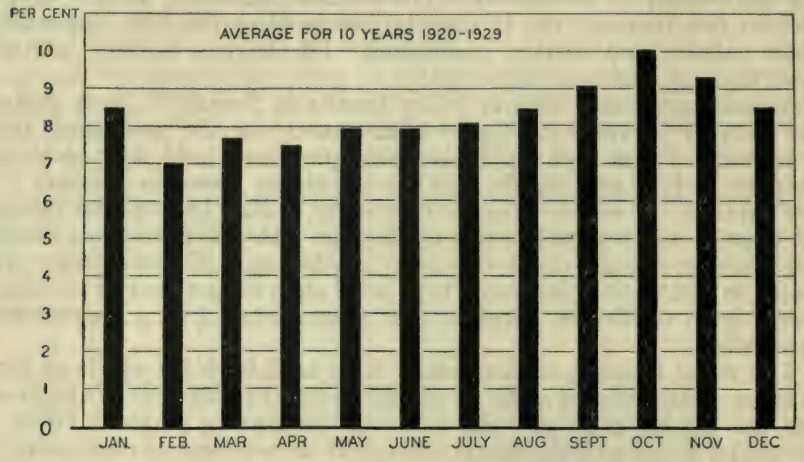

FIGURE 4.—CATTLE SLAUGHTERED UNDER FEDERAL INSPECTION, MONTHLY PERCENTAGE DISTRIBUTION OF AVERAGE YEARLY UNITED STATES TOTAL, 1920–1929

Cattle slaughter increases materially during September, October, and November. During this period Virginia cattle compete with grass cattle from all sections of the country

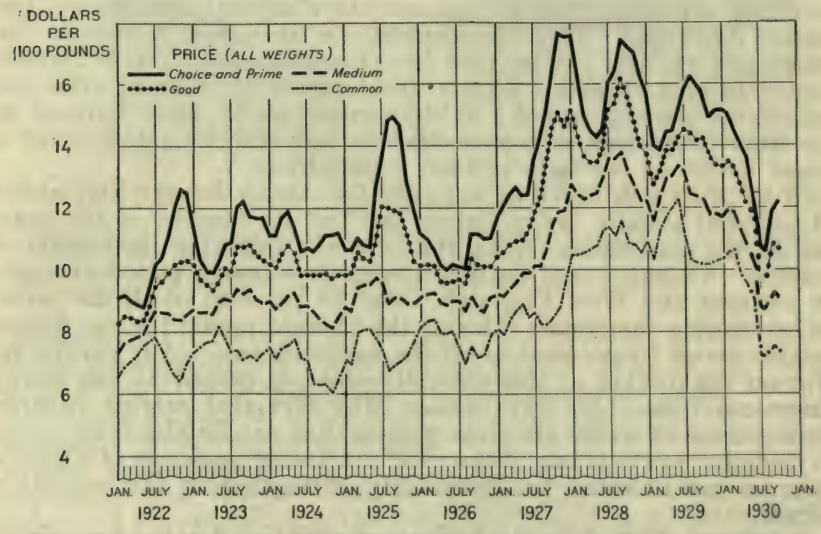

FIGURE 5.—PRICES OF BEEF STEERS SOLD OUT OF FIRST HANDS AT CHICAGO FOR SLAUGHTER (WESTERN STEERS EXCLUDED)

Prices of Choice and Prime steers fluctuate more violently than do prices of the lower grades. The seasonal fluctuations in prices of the different grades are determined to a great extent by the receipts of the different grades. The price of Choice and Prime beef steers is usually the highest in the late summer and fall months, when the supply is the smallest, and lowest in the spring months, when the supply is the greatest. The supply of Common steers is generally heaviest when the supply of Choice and Prime is lightest, and therefore the seasonal variation in the price for the Common is the opposite of the seasonal variation in the prices for Choice and Prime. In general, all grades of beef follow the same trend in prices, with the Medium showing the least fluctuation

the United States. Although many of these grass cattle are returned to feed lots for further finishing, a large number are slaughtered.

Figure 4 shows how slaughterings under Federal inspection increase during the period of the grass-cattle movement. With such greatly increased supplies of cattle of similar quality at this time it is natural to expect market prices for such cattle to decline somewhat. This seasonal decline in prices of grass cattle in the late summer and fall is shown in the prices for common and medium grade steers at Chicago during the years 1922–1926 and 1929. (Fig. 5.) The general rise in all cattle prices in 1927 and 1928, due to the sharp reduction in slaughter supplies, tended to prevent the usual seasonal declines in prices of these grades in those two years.

TABLE 6.—*Car-lot shipments of cattle from southwest Virginia, over the Norfolk & Western Railway, by months, 1922–1925*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
1922	21	12	13	18	72	154	230	352	717	800	143	43	2,575
1923	16	22	13	21	11	15	50	249	540	933	368	77	2,315
1924	26	7	9	15	8	12	49	226	513	966	527	114	2,472
1925	20	12	16	24	10	15	227	780	757	596	87	33	2,577
Average	21	13	13	20	25	49	139	402	632	824	281	67	2,485
Percentage of total	0.8	0.5	0.5	0.8	1.0	2.0	5.6	16.2	25.4	33.2	11.3	2.7	100

PRODUCTION RECORDS OF SELECTED SHIPMENTS OF VIRGINIA CATTLE

To acquire information on grazing and feeding requirements and marketing costs and to ascertain the suitability of Virginia cattle for trade demands, records were obtained of the feeding operations of a large number of graziers in southwest Virginia who expected to market cattle in the summer and fall of 1924. The steers included in the study were then followed through the market and slaughterhouse to the wholesale coolers, and detailed records were obtained on the cost of marketing each shipment. The first of these shipments reached Jersey City on August 17, and the last arrived there about the middle of November.

Complete finishing records for steers grazed in southwest Virginia for the season were obtained on 70 droves, totaling 4,203 head. Complete marketing records covered 52 cars, or 943 head, sold on the Jersey City market. A number of shipments were made direct to packers in Boston, Hoboken, and Philadelphia, but the records were too incomplete for analysis.

Because of their similarity in methods of handling cattle, Shenandoah Valley and north Virginia were considered as one area. In this area feeding records were obtained on 16 droves, totaling 679 steers, which were fed a ration consisting principally of silage and cottonseed meal during the winter of 1924–25. Complete market records were obtained on 18 carloads, or 358 head of these cattle during the period, December, 1924, to March, 1925.

The 86 droves in the two sections on which records were obtained in the summer of 1924 and the winter of 1924–25 were located according to counties as follows: In southwest Virginia—Washington 9, Smyth 19, Wythe 19, Pulaski 22, Montgomery 1; in the Shenandoah Valley and north Virginia—Augusta 4, Rockingham 3, Shenandoah 5, and Fauquier 4.

In 1926 the Virginia Agricultural Experiment Station in cooperation with the Bureau of Animal Industry and Bureau of Agricultural Economics carried on a route study in southwest Virginia to compare different methods of finishing cattle for market. The steers from the farms included in this study also were followed through the market, and marketing records were obtained thereon in a way similar to that in which those in 1924–25 were obtained.[2] These records, while in many cases not so complete as desired, covered a total of 58 carloads, or approximately 1,110 steers.

DESCRIPTION OF FARMS STUDIED

In southwest Virginia one or more droves of steers were finished on grass during the 1924 grazing season by each of the operators of the farms surveyed. The resulting data should not be considered as representative of the agriculture of the section as a whole, but of a particular class of farms. The finishing of steers on grass in this section is confined chiefly to rather large farms. The farms included in the survey ranged in size from 122 to 3,400 acres and averaged about 831 acres. On the smaller farms, few of which were included in this study, livestock production is usually relatively less important than on the farms surveyed. On these smaller farms a much higher proportion of the farm is cultivated, and crop sales are often of considerable importance.

The average size of farm for the different groups and distribution of the farm area are shown in Table 7. An average of about 18 per cent of the farm area was cropped; 64 per cent was pastured, and the rest was in woods not pastured and in waste land. But 12 per cent of the area of farms over 2,000 acres in size was cropped, and about 35 per cent was in woods not pastured and in waste land. On the smaller farms more of the land was cropped, and a smaller proportion was in woods not pastured and in waste land. According to estimates of operators of these farms, about 65 per cent of the total farm area was cultivatable; of this tillable land 72 per cent was in pasture and only 28 per cent in crops in 1923. It was estimated that an average of about 75 per cent of the pasture was cultivatable. Although most of the pastured land was designated as cultivatable and much of it can be easily tilled, considerable land designated as cultivatable is quite rolling and more or less broken and is of doubtful value for producing crops under ordinary conditions.

TABLE 7.—*Distribution of farm area of southwest Virginia livestock farms, by size of farm, 1923*

Acres in farm	Farms	Average size of farm	Crop land	Tillable pasture land	Pasture land not tillable	Woods and waste land
	Number	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
500 and less	24	357	91	190	49	27
501 to 1,000	27	698	135	361	125	77
1,001 to 2,000	9	1,469	271	738	236	224
Over 2,000	5	2,670	333	865	514	958
All farms	65	831	153	389	142	147

[2] The production phases of this route study are embodied in the following publication: LANGSFORD, E. L., and HUTSON, J. B., SYSTEMS OF BEEF CATTLE FARMING FOR SOUTHWESTERN VIRGINIA. Va. Agr. Expt. Sta. Bul. 258, 47 p., illus. 1927.

On some farms fertile and practically level bottom lands are grazed, whereas on other farms much of the land pastured is rolling to rough, and outcroppings of rock, usually of limestone origin, are conspicuous. Estimates were obtained from the operators of these farms as to the value of pasture land utilized for finishing steers. These estimates indicate that the average value of pasture land on the farms surveyed was about $125 per acre. On some farms the pasture land was valued at as little as $75 per acre; on other farms land pastured by feeders was valued at about $200 per acre. On about 85 per cent of the farms the estimated value ranged from $100 to $150 per acre.

Table 8 shows the number of farms reporting different kinds and classes of livestock and the average number of each kept on farms of different sizes. All of the farms surveyed kept feeder steers, and about half kept other steers. On most farms from 6 to 10 cows, usually of Shorthorn breeding, were kept. Sheep were kept on about 85 per cent of the farms. Usually from 60 to 150 ewes were kept, and the lambs were fattened and sold off grass in June and July. Hogs were kept on practically all farms. On most farms 3 to 8 brood sows were kept, and considerable income was derived from the sale of fat hogs and cured meats not needed for farm consumption.

TABLE 8.—*Livestock grazed on southwest Virginia farms studied during the 1924 season, by size of farm*[1]

Kind and class of livestock	500 acres and less		501 to 1,000 acres		1,001 to 2,000 acres		Over 2,000 acres	
	Farms reporting	Average[2] per farm	Farms reporting	Average[2] per farm	Farms reporting	Average[2] per farm	Farms reporting	Average[2] per farm
Cattle:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Feeder steers[3]	23	25.5	27	59.9	9	91.1	5	123.0
Other steers	14	7.3	15	10.6	4	37.8	4	44.0
Cows	23	4.8	25	5.3	8	7.6	4	9.6
Heifers	8	1.3	10	7.9	4	9.4	3	9.4
Calves	14	3.1	15	5.0	5	4.7	3	8.6
Bulls	5	.2	5	.2	5	2.7	2	1.0
Horses:								
Work stock	23	4.7	27	5.4	9	11.4	5	10.2
Other	14	1.4	16	2.3	6	3.7	3	3.2
Sheep:								
Ewes and rams	18	45.2	22	80.9	8	88.3	5	142.0
Lambs	18	48.9	22	89.0	8	89.0	5	137.7
Hogs:								
Brood sows	22	3.8	23	3.5	7	5.8	5	7.2
Other	18	12.3	26	23.0	9	45.3	5	36.0
Poultry, chickens, and turkeys	20	81.7	22	88.1	8	118.2	4	82.2

[1] There were 23 farms of 500 acres and less; 27 of 501 to 1,000 acres; 9 of 1,001 to 2,000 acres; and 5 farms of more than 2,000 acres. One farm of less than 500 acres in size which was included in Table 7 was omitted in calculating the above data because the feeder steers were grazed on hired pasturage.

[2] Averages are for all farms in the size group.

[3] Steers on farm during winter of 1923–24 and sold off grass during the late summer and fall of 1924.

Most of the farms surveyed could be classed as livestock farms. All of the grass, practically all of the hay, straw, stover, corn, and oats and part of the wheat were fed to livestock kept on these farms. On some farms extra feed, especially corn, and protein and mixed concentrates, was purchased. Of the crops produced in 1923 on the farms studied, feeder steers alone were fed 37 per cent of the corn, 20 per cent of the oats, 6 per cent of the wheat, 70 per cent of the corn stover, and 65 per cent of the straw, and, in addition, they con-

sumed 50 to 55 per cent of the grass. All classes of cattle utilized an average of more than 80 per cent of the grass on the farms surveyed. (Table 9.)

TABLE 9.—*Estimated amount of pasturage utilized by different kinds and classes of livestock on southwest Virginia farms studied, by size of farm, 1924 grazing season*[1]

Class of livestock	500 acres and less		501 to 1,000 acres		1,001 to 2,000 acres		Over 2,000 acres	
	Grazing units	Pasture grazed	Grazing units	Pasture grazed	Grazing units	Pasture grazed	Grazing units	Pasture grazed
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Feeder steers	30.6	49.3	71.9	57.6	109.3	52.4	147.6	55.8
Other steers	8.3	13.4	12.1	9.7	43.1	20.6	50.2	19.0
Other cattle	8.1	13.0	16.4	13.1	23.1	11.1	25.2	9.5
Total cattle	47.0	75.7	100.4	80.4	175.5	84.1	223.0	84.3
Horses	4.3	6.9	5.7	4.6	10.8	5.2	9.6	3.7
Sheep	8.8	14.2	15.7	12.6	16.8	8.0	26.8	10.1
Hogs	2.0	3.2	3.0	2.4	5.7	2.7	5.0	1.9
Total	62.1	100.0	124.8	100.0	208.8	100.0	264.4	100.0
	Acres		*Acres*		*Acres*		*Acres*	
Pasture land used	238.7		468.4		974.2		1,379.2	
Pasture per grazing unit[1]	3.8		3.8		4.7		5.2	

[1] By grazing unit is meant the equivalent of the grazing requirements of a beef cow during the grazing season. In the computations in the above table the grazing requirements of different classes of animals expressed in terms of this unit are as follows: Feeder steer 1.2, other steers 1.14, cows 1, heifers 1, calves 0.58, bulls 1.25, work stock 1.25, other horses and colts 1, sheep 0.15, lambs 0.08, brood sows 0.2, and other hogs 0.1. It was estimated that lambs and work stock were pastured during one-half of the grazing season.

The principal crops raised on the farms surveyed were hay, usually timothy and clover, corn, wheat, and oats. Of the crop land an average of 34 per cent was in hay; 28 per cent in corn; 26 per cent in wheat; 5 per cent in oats, and 7 per cent in truck, fruit, and miscellaneous crops. On most farms considerable income was derived from wheat, and some farmers sold some of their best hay. Cash income from other crops was of little importance since truck crops and fruit were produced for sale on but few farms.

The usual grazing season in southwest Virginia is from about April 15 to about December 1, but on some farms pastures are grazed practically throughout the year. Due largely to difference in the fertility of pasture land and to the length of grazing season and quantity of livestock kept, there was a considerable difference in the rate of stocking pastures on the farms surveyed. On the basis of all pasture land, the average amount of pasture land allowed per steer on these farms in 1924 ranged from 4.5 acres on farms 1,000 acres or less in size to about 6.2 acres on farms of over 2,000 acres. Many graziers reserve their best grasslands for finishing steers, the more unproductive pasture land being grazed largely by younger cattle, sheep, and horses. On some farms it was not possible to obtain accurate data relative to the amount of pasture utilized for finishing feeder steers, since steers were pastured either with other livestock or on various pastures. However, 58 of the 70 operators were able to give rather accurate information relative to the acreage of pasture land grazed by feeder steers. On 6 farms less than 3 acres were allowed per feeder steer, on 13 farms from 3 to 3.9 acres, on 17 farms from 4 to 4.9 acres, on 13 farms from 5 to 5.9 acres, and on 9

farms 6 or more acres were allowed per steer. The acreage of pasture allowed varied from 2.2 to 8 acres per steer, and averaged 4.5 acres on the farms surveyed.

Since only a small number of records were obtained on cattle-feeding operations in the Shenandoah Valley and north Virginia and the beef-cattle enterprise is much less important there than in southwest Virginia, no attempt was made to get detailed records of the farms in this section from which shipments were made.

The initial weight, breed, and quality of feeder steers in the droves studied were similar in both sections. Definite information regarding age of feeders when purchased was lacking, but estimates from finishers indicate that the steers were from 2 to 4 years of age and that the majority of animals were long 3s. In both sections late-maturing steers of Shorthorn breeding predominated. There were, however, a considerable number of Angus, Hereford, and crossbred steers and some that showed indications of dairy breeding.

CROP PRODUCTION AND MARKETING CONDITIONS, 1923 AND 1924

Favorable seasonal conditions prevailed in southwest Virginia during 1923, and favorable yields of corn and other crops were obtained. Favorable conditions continued in 1924, and pastures for finishing steers wintered on 1923 crops were uniformly good. In the Shenandoah Valley and north Virginia seasonal conditions in 1924 were somewhat unfavorable for corn. The yield per acre on most farms was much below normal. An extended drought during the early part of the season damaged much of the early corn, and late corn did not mature fully. Much of the corn was soft and otherwise of poor quality. The corn crop throughout the United States in 1924 was much below average in yield and quality and prices for corn were much higher in the winter of 1924–25 than in the preceding winter. Corn was charged to steers in southwest Virginia in the winter of 1923–24 at an average of 90 cents per bushel, whereas in the succeeding winter corn fed to steers in the Shenandoah Valley and north Virginia was charged at an average of $1.12 per bushel. This latter value was about 15 cents per bushel below the market price of good corn, but it was used because most feeders fed considerable corn of poor quality.

The poor corn crop throughout the country in 1924, together with unsatisfactory conditions in the cattle industry, resulted in rather heavy receipts of cattle at the principal markets in the fall of that year. With high prices for corn as a result of the small crop, the demand for feeder steers on the part of Corn Belt feeders was below average, and cattle that ordinarily would go back to the country for further finishing had no other outlet but the slaughterhouse. Under these conditions the cattle market was demoralized that fall, and most southwest Virginia steers which cost about $8 per 100 pounds as feeders in the fall of 1923 brought less than $7.50 at the farm when sold a year later. North Virginia and Shenandoah Valley feeders bought their feeder steers in the fall of 1924 and were able to obtain them at an average cost of about $6.25 per 100 pounds.

METHODS OF COMPILING COSTS AND LIMITATIONS OF COST DATA

In this study farm feeds were charged against steers at prevailing farm values at time of feeding. This farm value was usually computed by deducting the cost of marketing from the market value.

Cottonseed meal and other concentrates purchased were charged to steers at cost. Pasturage was charged to steers at different rates, depending on the quality of pasture. Summer and early fall pasturage was usually charged at prices ranging from $2 to $3 per steer month, and late fall and winter pasturage at from $0.50 to $1 per steer month. The averages of rates at which different items were charged are shown in Table 10.

TABLE 10.—*Averages of rates at which feed and other items were charged or credited in fattening steers, southwest Virginia, 1923–24, and Shenandoah Valley and north Virginia, 1924–25*

Item	Unit	Southwest Virginia, 1923–24	Shenandoah Valley and north Virginia, 1924–25
		Dollars	*Dollars*
Corn	Bushel	0.90	1.12
Other grain and miscellaneous concentrates	Ton	34.00	38.60
Hay	do	17.82	18.02
Stover	do	3.01	2.22
Straw	do	7.16	4.99
Silage	do	6.31	6.96
Summer pasture	Steer month	2.80	
Fall pasture	do	2.50	1.80
Winter pasture	do	.85	
Labor:			
Man	Hour	.175	.175
Horse	do	.125	.125
Credit for:			
Manure	Ton	1.32	1.93
Pork	Pound	.072	.10

Silage as charged includes the field value of corn used and the cost or value of labor, farm power, use of machinery, and other items necessary for filling the silo, together with repairs, depreciation, and interest on the silo.

Man labor was charged to steers at the average cost of this item on farms hiring labor in southwest Virginia in 1924. Information was obtained on southwest Virginia farms as to the amount and kind of labor hired and the cash expense and value of perquisites furnished. Horse work, an item of small importance, was charged at prevailing farm rates. Equipment costs include charges for normal repairs, depreciation, and taxes and a return of 6 per cent on the value of all cattle equipment, including feeder barns, feed lots, fences, wagons, and all other equipment. "All other costs" include taxes, expense for veterinary service, insurance, death loss or risk, and other miscellaneous items. Risk or death loss was of little importance. Death losses in southwest Virginia totaled 23 head out of the 4,226 steers included in the survey. There were no losses from death in the Shenandoah Valley or in north Virginia.

Cost-of-production studies conducted in various beef-cattle finishing sections indicate that there are considerable variations from year to year in the cost of finishing steers. The chief cause of variation, assuming that feeding practices and feeder animals are similar, is usually found in the differences in the cost of feed. Items like man labor and horse work are usually of minor importance and are much less subject to extreme changes in value.

In presenting the data obtained in this study on the cost of grazing and feeding steers the authors are well aware of the limitations of the

data. The data as presented summarize the fiscal results for a specific year, and market returns during the period of the study, particularly for cattle fed in southwest Virginia were very unsatisfactory to the finishers. Furthermore, there are charged to the steers items which can be evaluated only with difficulty. Outstanding examples of these items are pasturage, stover, and straw. Most of the graziers had no other method of marketing these products except as beef, consequently the value of the items depended largely on the demand for them by the graziers themselves.

The amounts of feed, labor, horse work, and other items indicated for the different methods of feeding are believed to be representative of feeding practices in the sections studied; and a fairly accurate estimate of the cost of wintering or fattening steers by the different methods for any specific year can be made by evaluating these requirements at rates prevailing for the various items during the feeding period.

RESULTS OF DIFFERENT METHODS OF WINTERING AND FATTENING STEERS

In southwest Virginia steers were kept on pasture until December 1, or later, depending on weather conditions. About 75 per cent of the steers were wintered on a ration consisting principally of shock corn, hay, and straw. In this bulletin these steers are called "nonsilage" steers. The remaining droves were wintered on silage and lesser quantities of grain and dry roughage and are referred to as "silage" steers. A few of the droves were fed in small feed lots, but these usually had the run of small pasture lots or fields from 5 to 20 acres in size.

The quantity of corn and other feeds fed to steers on different farms varied considerably. Some feeders fed as much as 20 bushels of corn per steer besides other concentrates; others fed mostly hay, corn stover, and straw, and but little grain during the winter period. About April 20, steers were turned on grass and were given no additional feed during the pasture season.

In the Shenandoah Valley and in north Virginia all of the steers on the farms surveyed were fed silage, cottonseed meal, and usually other concentrates and roughage, and were confined in small feed lots during the feeding period. In these sections feeders procured their feeder animals from October to December and usually fed them from 75 to 110 days before marketing them.

Southwest Virginia nonsilage steers were fed an average of about 14 bushels of corn, over 90 pounds of other grain and miscellaneous concentrates, about three-quarters of a ton of hay, approximately the same quantity of stover, and about 700 pounds of straw per steer during the winter period. (Table 11.)

Silage steers on an average were fed about 3,500 pounds of silage per steer and were fed smaller quantities of grain and dry roughage than were fed to nonsilage steers. Pork production was almost in direct proportion to the quantity of corn fed and much less for silage than for nonsilage steers. Manure credits were somewhat higher for silage than for nonsilage steers, as silage steers were confined to a greater extent during the winter feeding period.

TABLE 11.—*Results of different methods of wintering and finishing steers in southwest Virginia, 1923–24 and in north Virginia and Shenandoah Valley, 1924–25*

Item	Unit	Southwest Virginia grass-finished steers, 1923–24, wintered on—				North Virginia and Shenandoah Valley dry-lot steers, 1924–25, finished on silage ration	
		Nonsilage ration		Silage ration			
			Dollars		*Dollars*		*Dollars*
Droves	Number	53		17		16	
Steers sold	do	3,137		1,066		679	
Days on farm	do	372		391		89	
Initial weight per steer	Pounds	1,123		1,124		1,155	
Gain per steer	do	293		309		181	
Daily gain per steer	do	.80		.79		2.03	
Cost per head, of finishing:							
Winter feed—							
Corn	Bushels	13.9	12.52	6.5	5.65	7.4	8.26
Other grains and concentrates	Pounds	89	1.51	18	.33	30	.58
Protein concentrates	do	4	.10	30	.69	336	8.31
Hay	do	1,501	13.17	592	5.83	563	5.07
Corn stover	do	1,665	2.47	1,033	1.61	323	.36
Straw	do	711	2.50	653	2.46	1,172	2.93
Silage	do			3,447	10.88	4,357	15.16
Total cost of winter feed			32.27		27.50		40.67
Pasture:							
Summer	Steer days	171	15.94	186	17.15		
Fall	do	69	5.72	67	5.65	7	.41
Winter	do	36	1.01	25	.70		
Salt	Pounds	29	.35	25	.29	9	.11
Total cost of feed			55.29		51.29		41.19
Man labor	Hours	19.5	3.42	17.8	3.11	10.6	1.85
Horse labor	do	21.6	2.70	12.6	1.57	3.2	.40
Equipment			1.27		1.67		4.77
Interest			5.54		5.79		1.06
Taxes			1.08		1.01		.16
Miscellaneous			.97		.62		.27
Total			70.27		65.06		49.70
Credit for—							
Pork produced	Pounds	21	1.51	7	.49	12	1.18
Manure	do	1,573	1.00	2,003	1.45	6,480	6.26
Total			2.51		1.94		7.44
Net cost of finishing steer			67.76		63.12		42.26
Initial cost			90.52		89.93		73.09
Net cost of finished steer at farm.			158.28		153.05		115.35
Sales value at farm			105.28		103.81		111.44
Loss			53.00		49.24		3.91
Initial cost per 100 pounds			8.06		8.00		6.33
Sales price per 100 pounds home weight			7.41		7.24		8.34
Margin [1]			−.65		−.76		2.01
Margin required to cover costs			3.08		2.68		2.30
Cost per 100 pounds gain			22.74		20.43		23.35

[1] Where sales price per 100 pounds at farm was less than purchase price a minus (−) is shown.

There appears to be but little difference in so far as gain or economy of gain is concerned (on the basis of values such as prevailed during the period of the study) between the two methods of wintering steers in southwest Virginia. The slight differences that occur appear to favor the feeding of silage rations in preference to one of grain and dry roughages. The cost of feed, including pasturage, was about $4 less per steer for silage than for nonsilage steers. This amount represents the apparent advantage of a silage ration as compared with a nonsilage ration during the period of the study.

The feeder steers for which records were obtained in north Virginia and in the Shenandoah Valley were similar in quality and weight to southwest Virginia feeder steers. During an average feeding period of about 90 days these steers, while receiving the same quantity of hay and other dry roughage, were fed about 900 pounds more silage, about 1 bushel more corn, and about 300 pounds more protein concentrates per head than were fed to steers wintered on silage in southwest Virginia. Pork and manure production averaged higher and less labor and horse work was expended per steer than in southwest Virginia. Principally because of the low initial cost of feeder steers, the feeding operations for these short-fed steers, although somewhat unsatisfactory, were much less unfavorable than in the southwest Virginia section. The short-fed steers made an average gain of about 2 pounds per steer per day, as compared with about 0.8 pound for steers finished on grass in southwest Virginia. The cost per 100 pounds gain was practically the same for both the dry-lot steers and those finished on grass which were wintered on a nonsilage ration. Feed prices, particularly prices for corn, however, were somewhat higher in the Shenandoah Valley and north Virginia sections than in southwest Virginia.

The average weight of southwest Virginia steers when obtained as feeders was about 1,125 pounds; from 65 to 70 per cent of the droves ranged from 1,100 to 1,200 pounds. Results for southwest Virginia silage and nonsilage steers for different weights are shown in Table 12. Graziers who wintered feeder steers of less than usual weight had a tendency to feed them much less grain and silage during the winter period than was usually fed to heavier steers. Of the nonsilage steers, those weighing from 900 to 1,000 pounds when purchased made the best and most economical gain, and the margin required to pay all costs was appreciably less than for heavier steers. No apparent relationship is indicated between silage steers of different weight in so far as gain, economy of gain, and margin required to pay all costs of the feeding operation are concerned. This is probably because of the small number of droves in some of the weight groups.

In the Shenandoah Valley and north Virginia sections, steers included in the lighter-weight group made the best and cheapest gain, and less margin was required for them than for steers in the heavier group. (Table 13.) Steers in both weight groups were on feed about the same number of days, but the steers in the heavier group were fed considerably more dry roughage and somewhat more grain and concentrates than the lighter steers.

TABLE 12.—*Feed and labor used and cost per steer for wintering and grazing southwest Virginia grass-finished steers, by method used in feeding and by initial group weight of steers, 1923–24*

Item	Unit	Steers fed nonsilage ration				Steers fed silage ration			
		900–1,000 pound	1,001–1,100 pound	1,101–1,200 pound	1,201–1,300 pound	900–1,000 pound	1,001–1,100 pound	1,101–1,200 pound	1,201–1,300 pound
Droves	Number	5	14	31	3	3	3	9	2
Steers sold	do	164	691	1,910	372	94	146	721	105
Days on farm	do	384	390	366	365	368	385	388	438
Initial weight at farm	Pounds	964	1,052	1,141	1,233	949	1,063	1,142	1,232
Gain per steer	do	325	318	296	255	319	326	304	321
Grain:									
Corn (shelled)	do	312	719	1,110	1,015	434	528	486	180
Miscellaneous concentrates	do	-------	232	98	230	-------	-------	36	-------
Protein concentrates	do	-------	-------	7	-------	-------	55	22	76
Roughage:									
Hay	do	822	1,660	1,471	1,647	766	342	693	87
Other dry roughage	do	3,318	2,112	2,430	2,078	2,172	1,519	1,821	514
Silage	do	-------	-------	-------	-------	3,917	4,414	3,967	6,138
Pasture	Steer days	254	315	263	230	236	271	274	360
Man labor	Hours	15.3	18.4	19.8	21.7	31.3	10.8	17.6	15.7
Horse labor	do	12.0	19.1	21.6	29.6	18.5	8.2	14.0	2.6
Credits:									
Pork	Pounds	4.5	13.0	24.3	23.7	1.6	2.3	9.1	1.3
Manure	do	1,365	1,030	1,157	5,365	2,236	2,259	1,894	2,189
Financial results:									
Initial cost at farm	Dollars	73.74	83.21	92.08	103.50	72.77	83.28	92.54	96.53
Feed cost, including pasturage	do	45.76	55.81	54.77	61.11	47.37	48.35	52.06	53.57
All other costs	do	10.96	14.42	14.88	18.00	15.28	10.86	14.31	12.80
Manure and pork credit	do	.91	1.47	2.47	5.38	1.94	1.33	2.18	1.20
Net cost of finished steer at farm	do	129.55	151.97	159.26	177.23	133.48	141.16	156.73	161.70
Initial cost per 100 pounds	do	7.65	7.91	8.07	8.40	7.67	7.83	8.10	7.84
Sales price per 100 pounds, home weight	do	6.89	7.27	7.42	7.80	7.29	7.30	7.18	7.54
Margin received [1]	do	−.76	−.64	−.65	−.60	−.38	−.53	−.92	−.30
Margin required to pay all costs	do	2.40	3.18	3.01	3.51	2.86	2.33	2.74	2.57
Cost per 100 pounds gain	do	17.17	21.62	22.70	28.91	19.03	17.75	21.12	20.30

[1] Minus (−) means that selling price per 100 pounds was less than cost.

Southwest Virginia graziers usually expect to dispose of their grass-finished steers at any time from the latter part of July until October, depending principally on grazing and marketing conditions. During the year of the study, market conditions were decidedly unfavorable, and feeders held their steers for a longer time than usual, hoping for a stronger market. But steers kept back brought somewhat lower prices than did steers sold earlier. (Table 14.) On an average, steers kept on the farm less than 350 days made the best gain. These steers received more grain but less silage than did steers included in the other groups. The extra expense for keeping steers over the longer period is largely for pasturage, and if the feeder has no alternative use for his grass this item is a doubtful charge under these conditions. It appears, however, that there was no apparent advantage in holding steers over the longer period, for gains were apparently slightly favorable to steers kept on the farm for the shorter period.

TABLE 13.—*Feed and labor used and cost per steer for fattening north Virginia and Shenandoah Valley steers of different weights, 1924–25*

Item	Unit	Steers weighing—	
		1,150 pounds or less	Over 1,150 pounds
Droves	Number	9	7
Steers sold	do	333	346
Days on farm	do	86	91
Initial weight at farm	Pounds	1,101	1,207
Gain per steer	do	200	163
Grain:			
Corn (shelled)	do	386	437
Miscellaneous concentrates	do	13	46
Protein concentrates	do	278	392
Roughage:			
Hay	do	282	834
Other roughage	do	1,631	1,365
Silage	do	4,287	4,424
Pasture	Days	4	10
Man labor	Hours	9.8	11.3
Horse labor	do	2.4	4.0
Credits:			
Pork	Pounds	10.7	13.1
Manure	do	5,766	7,168
Financial results:			
Initial cost at farm	Dollars	69.27	76.76
Feed cost	do	36.09	46.10
All other costs	do	7.25	9.72
Total costs	do	112.61	132.58
Manure and pork credit	do	7.03	7.85
Net cost of finished steer at farm	do	105.58	124.73
Initial cost per 100 pounds	do	6.29	6.36
Sale price per 100 pounds, home weight	do	8.29	8.39
Margin received [1]	do	2.00	2.03
Margin required to pay all costs	do	1.83	2.74
Cost per 100 pounds gain	do	18.16	29.43

[1] Sales price per 100 pounds minus initial cost.

TABLE 14.—*Relative cost and gain of grass-finished steers by number of days kept on farm in southwest Virginia, 1923–24*

Item	Unit	Steers kept less than 350 days		Steers kept 350–399 days		Steers kept 400 days and over	
			Dollars		*Dollars*		*Dollars*
Droves	Number	11		51		8	
Steers sold	do	663		3,123		417	
Days on farm	do	341		378		424	
Initial weight per steer	Pounds	1,130		1,121		1,124	
Gain per steer	do	316		296		314	
Daily gain per steer	do	.93		.78		.74	
Cost per head of finishing:							
Winter feed—							
Corn	Bushels	15.5	13.53	12.4	11.10	3.7	3.92
Miscellaneous concentrates and other grain	Pounds	91	1.53	79	1.46	77	1.36
Hay	do	1,704	13.34	1,218	11.03	969	10.24
Other dry roughage	do	2,139	4.07	2,249	4.97	1,667	4.15
Silage	do	121	.29	745	2.27	3,037	10.38
Salt	do	20	.23	29	.35	29	.34
Pasture	Steer days	250	18.49	272	22.82	344	30.25
Total cost of feed			51.48		54.00		60.64
Net cost of finishing steer			61.99		66.41		74.75
Initial cost per steer			90.61		90.37		89.99
Net cost of finished steer at farm			152.60		156.78		164.74
Initial cost per 100 pounds			8.02		8.06		8.01
Sales price per 100 pounds, home weight			7.81		7.31		7.09
Margin received [1]			−.21		−.75		−.92
Margin required to pay all costs			2.53		3.00		3.45
Cost per 100 pounds gain			19.62		22.44		23.81

[1] Minus (−) means that selling price per 100 pounds was less than initial cost.

The steers fed in north Virginia and in the Shenandoah Valley would be classed as short-fed or "warmed-up" steers at middle-western markets. Four of the 16 droves were fed for less than 75 days, or an average of about 60 days, and the remaining 12 droves were on feed approximately 100 days. Steers kept on the farm for the shorter period, which is not long enough to permit finishing, made much better gain per steer per day and at less cost, and less margin was required to pay all cost than was required for steers fed the longer period. (Table 15.)

TABLE 15.—*Relative cost and gain of grass-finished steers, by number of days kept on farm in north Virginia and Shenandoah Valley, 1924–25*

Item	Unit	Steers kept less than 75 days		Steers kept over 75 days	
			Dollars		*Dollars*
Droves	Number	4		12	
Steers sold	do	142		537	
Days on farm	do	59		97	
Initial weight per steer	Pounds	1,125		1,163	
Gain per steer	do	154		188	
Daily gain per steer	do	2.6		1.9	
Cost per head of finishing:					
Winter feed—					
Corn	Bushels	3.0	4.22	8.5	9.33
Miscellaneous concentrates and other grain	Pounds	24	.45	32	.62
Protein concentrates	do	268	6.27	354	8.84
Hay	do	144	1.43	674	6.04
Other dry roughage	do	1,084	2.71	1,604	3.43
Silage	do	4,137	12.93	4,415	15.75
Salt	do	7	.09	9	.12
Pasture	Steer days			9	.52
Total cost of feed			28.10		44.65
Net cost of finishing steer			29.41		45.65
Initial cost per steer			74.72		72.65
Cost of finished steer at farm			104.13		118.30
Initial cost per 100 pounds			6.64		6.25
Sale price per 100 pounds, home weight			7.94		8.44
Margin received			1.30		2.19
Margin required to pay all costs			1.50		2.51
Cost per 100 pounds gain			19.10		24.28

MARKETING RECORDS OF STEERS FROM SELECTED DROVES

When the steers from the selected droves were shipped to market they were followed from the shipping point through the terminal market, where information was obtained on marketing costs, shrinkage in transit, market fill, and grade and selling price. Table 16 summarizes the information, together with that obtained regarding the cattle marketed from the farms included in the route study in southwest Virginia in 1926. From the terminal market the cattle were followed through the slaughtering plant to the wholesale coolers to obtain information on dressing percentage, grade and color of carcass, and the wholesale value of the final product. Unfortunately it was impossible to get complete resords, particularly slaughtering records, regarding shipments sent to markets other than Jersey City. But the steers sold at Jersey City were fully representative of all the fat cattle marketed from Virginia. Most of the cattle marketed from the farms included in the route study in 1926 were sent to Lancaster. The local representative of the Pennsylvania Bureau

of Markets gave all possible assistance in getting information regarding these cattle, but many of them were sold to butchers and slaughterers who operate on a small scale and keep no records; hence little reliable slaughter information was obtained.

TABLE 16.—*Shrinkage, market fill, and cost of marketing steers shipped from Virginia, 1924–1926*

Item	Unit	Steers from southwest Virginia, summer and fall, 1924			Steers from north Virginia, winter, 1924–25			Steers from southwest Virginia, summer and fall, 1926		
		Per car	Per steer	Per 100 pounds shipping weight	Per car	Per steer	Per 100 pounds shipping weight	Per car	Per steer	Per 100 pounds shipping weight
Shipping weight	Pounds	26,116	1,440		26,663	1,341		25,723	1,280	
Arrival weight	do	23,715	1,308		24,201	1,217		23,473	1,168	
Shrinkage in transit	do	2,401	132	9.2	2,462	124	9.2	2,250	112	8.7
Market fill	do	1,163	64		1,340	67		920	46	
Selling weight	do	24,878	1,372		25,541	1,284		24,393	1,214	
Net shrinkage	do	1,238	68	4.7	1,122	57	4.2	1,330	66	5.2
Time in transit	Hours	64						[1] 55		
Time held in yards	do	38			49			[1] 40		
Marketing costs:										
En route—										
Bedding	Dollars	1.30			[2] 2.04			([3])		
Freight	do	128.12			100.25			122.66		
Feed	do	3.96			4.96			4.05		
Total	do	133.38	7.35	.51	107.25	5.39	.40	126.71	6.31	.49
At terminal market—										
Hay	do	[4] 20.14	1.11	.07	[5] 20.11	1.01	.08	12.12	.60	.05
Commission	do	22.67	1.25	.09	24.86	1.25	.09	24.89	1.25	.10
Yardage	do	7.25	.40	.03	7.96	.40	.03	3.01	.15	.01
Fire insurance	do	.20	.01		.20	.01		.15		
Total	do	50.26	2.77	.19	53.13	2.67	.20	40.17	2.00	.16
Shrinkage [6]	do	102.45	5.65	.40	103.24	5.19	.39	118.12	5.88	.46
Total costs:										
Excluding shrinkage	do	183.64	10.12	.70	160.38	8.06	.60	166.88	8.31	.65
Including shrinkage	do	286.09	15.77	1.10	263.62	13.25	.99	285.00	14.19	1.11

[1] Based on all lots having complete data.
[2] Includes long-distance telephone calls and reconsignment charges incurred on shipments reconsigned from Baltimore.
[3] Included with freight charges.
[4] Cost of 959 pounds, average amount fed per car.
[5] Combined cost of 772 pounds of hay and 2.3 bushels of corn; average amount fed per car.
[6] Home weight minus sales weight times prices.

GRASS-FINISHED STEERS FROM SOUTHWEST VIRGINIA IN 1924

Data presented in Table 16 on steers shipped in the summer and fall of 1924 are based on the averages for 52 cars, or 943 steers, that sold for an average of $8.28 per 100 pounds. The time in transit to Jersey City was 64 hours, including a stop-over for feed, water, and rest at Hagerstown, Md. The cattle, on an average, remained in the yards 38 hours before they were weighed to the buyer. The range in average selling weights by carloads was from 1,241 to 1,471 pounds per head, and the amount available for sale out of the original 100 pounds loaded ranged from 93.4 to 98.2 pounds. The net shrinkage for the individual cars varied from 1.8 to 6.6 pounds per 100 pounds shipping weight, but the average of 4.7 pounds is typical. In some cases excessive market fills were reported, thus affecting the net shrinkage to some extent. The market fill per steer varied

from 34 to 107 pounds per head, depending somewhat on the time in the yards and the weight of the steer. The gross shrinkage in transit varied from 6.6 to 12.2 pounds per 100 pounds shipping weight, but the average of 9.2 pounds is typical of the major portion of the cars followed through the Jersey City market. The freight rate ranged from 53 to 55½ cents per 100 pounds arrival weight, with a minimum weight of 22,000 pounds for cars 36 feet 7 inches and under.

Although loss in weight or shrinkage in transit can hardly be included as a cost item in marketing since, on the average, proper allowance is made for it by buyer and seller, it must be given consideration by the shipper, particularly if it proves to be above average on individual shipments. If shrinkage is considered a marketing expense it represents the second largest item in marketing cattle from southwest Virginia to Jersey City. In computing the allowance for shrinkage it is assumed that the animal would sell for the same price per 100 pounds regardless of the amount of shrinkage, but this is hardly to be expected. Shrinkage cost as computed is subject to considerable variation because of variations in the market value of the animal. With no change in the rate of shrinkage, the higher the value of the animal the higher the shrinkage cost would be.

With higher cattle prices, such as prevailed in 1928 and 1929, marketing costs would be increased proportionally if the item of shrinkage is considered as a cost of shipping. Excluding shrinkage, most of the marketing charges are subject to little variation, especially freight, commission, and yardage charges. Feed charges have more variation, mainly because of the length of time cattle are held in the stockyards before being sold. Charges for feed at the terminal market in 1924 varied from $5.60 to $44.57 per car. Shrinkage cost is subject to the widest variation, because of the variations in both the amount of net shrinkage and the value placed on it. The shrinkage charges for the 52 cars studied ranged from $39.10 to $151.30 per car. The total marketing charges per 100 pounds shipping weight varied from 92 cents to $1.27 for the different cars. The total charges on 30 per cent of the cars varied from $1.10 to $1.15 per 100 pounds shipping weight.

FED CATTLE FROM NORTH VIRGINIA, 1924–25

Market records were obtained on 18 carloads or 358 head of fed cattle shipped from the Shenandoah Valley and north Virginia to Jersey City in the winter of 1924–25. The averages shown on these cattle may not be as representative of actual conditions as they would be if they included a larger number of shipments, but they check closely with the information obtained on southwest Virginia cattle.

Cars from the north Virginia section were loaded somewhat heavier, both as to weight and number of cattle, than were those from southwest Virginia. They averaged about 20 steers per car, and the average weight per car was 26,663 pounds at shipping point. Shrinkage in transit was slightly less per head than the shrinkage on the cattle from southwest Virginia but since the north Virginia cattle were about 100 pounds lighter per head, the shrinkage per 100 pounds shipping weight was the same, 9.2 pounds. The north Virginia cattle took on a much larger market fill, thus reducing the net shrinkage to 4.2 pounds per 100 pounds shipping weight as compared with the 4.7 pounds on the cattle from southwest Virginia.

Approximately one-half of the shipments were reconsigned from Baltimore, and in several cases they had heavy feed charges at that market. A few shipments carried charges for feeding in transit at Baltimore. The charge for feed en route, $4.96, is an average of the feed charges for all shipments and is subject to considerable variation according to whether the cattle are fed in transit and whether they are offered for sale at Baltimore before being sent on to Jersey City. Charges listed under bedding include besides bedding costs such items as telephone calls and reconsignment charges. The two latter items need not be incurred unless the shipper feels that a higher price can be obtained by reconsigning.

As terminal marketing costs are largely on a head basis at Jersey City there is little variation in these costs for cattle from different sections. With a larger number of cattle per car in the shipments from north Virginia the terminal charges on a carload basis were somewhat higher than those on the southwest Virginia cattle. The feed charges per car were practically the same, so the average feed charge per head was slightly less than for the southwest Virginia cattle. The average feed consumed per car was 772 pounds of hay and 2.3 bushels of corn. Feed charges at Jersey City at the time these shipments were marketed were $2 per 100 pounds for hay and $2 per bushel for corn. The net shrinkage of north Virginia cattle was less than that of the cattle from southwest Virginia, but their average selling price was $9.20 per 100 pounds, as compared with $8.28 for the latter. The lower shrinkage of the north Virginia cattle was balanced therefore by a somewhat higher selling price, making the shrinkage charges in either case about the same.

STEERS MARKETED AT LANCASTER FROM SOUTHWEST VIRGINIA IN 1926

Fifty-eight cars were followed from farm to market in 1926, practically all the shipments being consigned to Lancaster, but complete records were obtained on only 11 cars. The steers in these 11 cars were of lighter weight than those marketed at Jersey City in 1924 and 1925. This was to be expected in view of the common practice in southwest Virginia of marketing the lighter cattle at Lancaster, where there is a feeder demand as well as a slaughter outlet. With an average of 20.1 steers per car, the average shipping weight was 25,723 pounds per car, or 1,280 pounds per head. Average gross shrinkage in transit amounted to 2,250 pounds per car, or 112 pounds per head. Expressed as a percentage of the shipping weight, this amounted to 8.7 per cent, or 0.5 per cent less than the gross shrinkage on the shipments made in 1924–25. The market fill on these steers was considerably less than that on those shipped in 1924–25, amounting to only 3.9 per cent of the arrival weight, as compared with 4.9 per cent on the steers shipped from southwest Virginia in 1924 and 5.5 per cent on those shipped from north Virginia in 1924–25.

Net shrinkage on the cattle going to Lancaster was slightly greater than that on those going to Jersey City in 1924–25, largely because of the smaller fill obtained. The cattle shipped to Lancaster were in transit an average of 55 hours, as compared with 64 hours for those going to Jersey City. After arrival at Lancaster the steers were held in the yards 40 hours before sale was made. At Jersey City this time averaged 38 hours.

Total shipping costs to Lancaster were almost 2 cents per 100 pounds less than the cost of shipping to Jersey City. Terminal-market costs at Lancaster were slightly lower than those at Jersey City. Commission charges were the same at both markets, being $1.25 per head. Yardage charges at Lancaster were 15 cents a head, as compared with 40 cents at Jersey City. Total feed costs at Lancaster were only about 60 per cent of those at Jersey City. This was due largely to the fact that smaller quantities of hay were fed although unit costs were also slightly lower.

Without making any allowance for shrinkage, the total cost of marketing cattle from southwest Virginia at Lancaster was 65 cents per 100 pounds shipping weight, as compared with 70 cents for those sold at Jersey City. Applying the selling value of the cattle to the net shrinkage in weight and considering net shrinkage as a market cost, the total average marketing cost was increased to $1.11, which is practically the same as the total average cost of marketing at Jersey City in 1924. When including shrinkage, the comparative cost figures are not exactly comparable because the level of cattle prices in 1926 was higher than in 1924. After the 1924 selling price of cattle at Jersey City has been adjusted to the 1926 level, which amounted to an increase of 6.7 per cent, the average total cost of marketing cattle at Jersey City amounts to $1.12 per 100 pounds of shipping weights, as compared with an average total cost of $1.11 at Lancaster.

SLAUGHTER INFORMATION REGARDING CATTLE FOLLOWED TO MARKET

After the selected lots of cattle marketed in 1924 and 1925 were sold at Jersey City, they were followed through the slaughter plants to the wholesale coolers, and information was obtained regarding the yield and general quality of the beef produced. In this phase of the study, information was obtained regarding the length of time the cattle were held by the buyer before slaughter, the dressing percentage, grade and selling price of carcass, number or percentage of dark-cutting carcasses, and yield and grade of hide. Because of the difficulty of maintaining the identity of the various lots through the slaughterhouse, complete records were obtained on only 73 cars, or 1,337 head, of southwest Virginia cattle, and 22 cars, or 437 head, of north Virginia cattle.

Southwest Virginia steers dressed on an average 56.32 per cent of their selling weight. In other words, a steer of the average weight, 1,372 pounds, produced a carcass weighing about 773 pounds. The range in dressing percentage was 53.55 to 58.50 per cent, with approximately 70 per cent of the cattle dressing between 55 and 57.5 per cent. Steers from north Virginia dressed on an average 55.17 per cent. The difference in dressing percentage of the cattle from the two sections may be within the error of sampling, but the lighter weight of the north Virginia cattle and their somewhat greater market fill probably accounts for their yield being slightly less than that of the cattle from southwest Virginia. Approximately 70 per cent of the north Virginia steers dressed between 54 and 56.5 per

cent. The cool weight, which is about 2.5 per cent less than the warm weight, was used in computing the dressing percentage or carcass yield of each group. These percentages are in line with what can be expected from steers of such grade and weight. The market fill, which is generally very high at Jersey City because of the long time that cattle are held there before being offered for sale, tends to lower the carcass yields. The dressing percentage of southwest Virginia steers declined somewhat as the season advanced. This indicated that the better cattle were marketed earlier, which is in accordance with the general practice of "topping-out' herds and leaving the inferior animals to be marketed last.

In both groups the carcasses graded much in line with the live animals. The steers from north Virginia graded somewhat higher than those from southwest Virginia. Approximately 85 per cent of those from the latter section graded from average Medium to low Good for both the live animal and the carcass. The other 15 per cent graded down to the low end of Medium, with a few individual steers grading as low as Common. Practically all the steers from north Virginia graded from average Medium to average Good with a large proportion in the upper range. They showed more quality, had better conformation, were younger and lighter, and seemed to meet the trade requirements much better than did the steers from southwest Virginia. Market and trade conditions, however, were more favorable during the period in which they were marketed, and this may partly account for the fact that they sold for 92 cents per 100 pounds more than did the steers from southwest Virginia. A more complete discussion of the seasonal variations in the supply and price of cattle by grades appears elsewhere in this bulletin.

Figure 6 shows the selling price of the various lots of cattle and the price range of Medium grade heavy steers at Jersey City at the time they were marketed. The average selling price of the carcasses was $15.09 per 100 pounds for the north Virginia steers and $13.25 for the steers from southwest Virginia. The carcass prices held about the same relationship as was noted in the live cost. Carcass prices showed considerable variation, largely because of color, weight, and grade of carcass, and market conditions at the time of sale. All the cattle were kosher slaughtered, but approximately 15 to 20 per cent of the carcasses failed to meet the Jewish requirements. Failure to meet these requirements did not necessarily make the meat objectionable for the non-Jewish trade.

The relative value of Virginia cattle is enhanced slightly by the weight and grade of hide obtained. Information was obtained on the weight, percentage, and grade of hides taken from the steers that were followed through the slaughterhouses. The hides were classed largely as spready and heavy natives. Around 80 per cent graded as No. 1. The hide represented about 6 per cent of the live weight of the steer, and for the heavy steers amounted to about 80 to 85 pounds. Very few branded hides were observed. Hides from koshered cattle may sell at a slight discount because of the methods of slaughtering.

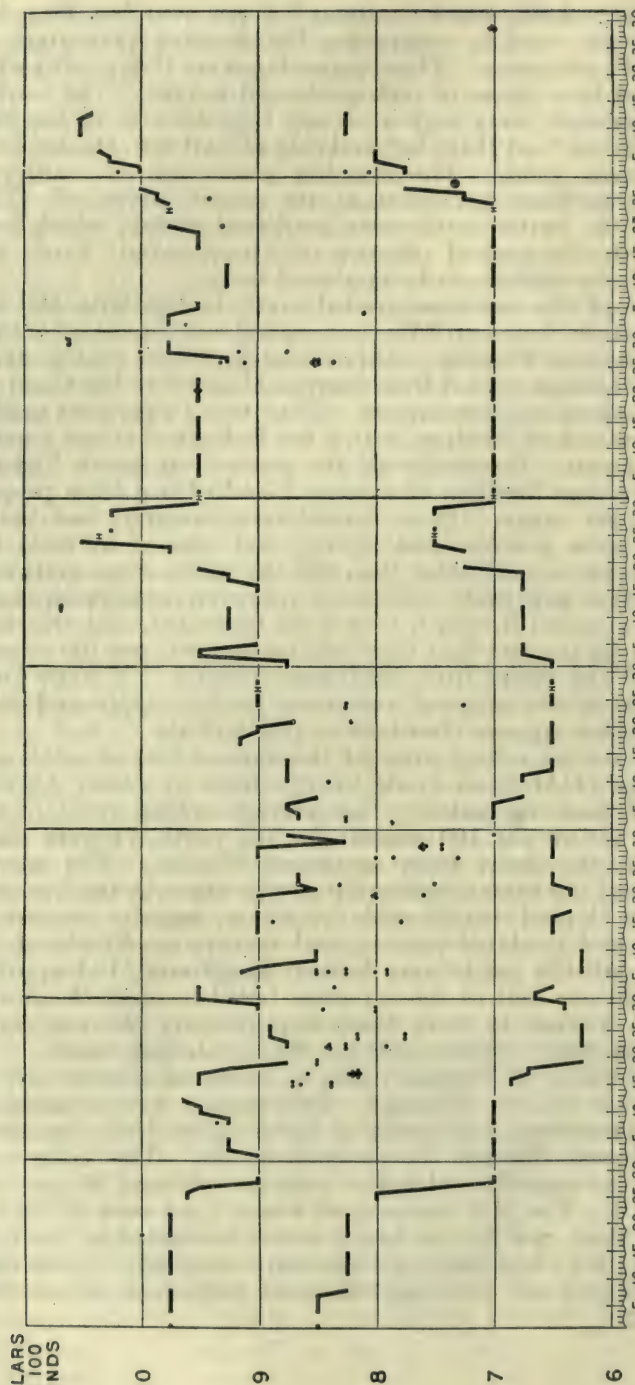

FIGURE 6.—SALES OF VIRGINIA CATTLE AT JERSEY CITY

The space between the heavy broken lines represents the range of market prices for Medium grade steer at Jersey City during the period in which the selected shipments were sold. Each dot represents the selling price of a car lot of Virginia cattle followed through the Jersey City market. Those in 1924 were grass cattle from southwest Virginia and those in 1925 were fed cattle from north Virginia

MARKETING COSTS OF COMPETING CATTLE

Since eastern slaughterers buy many of their cattle at midwestern markets, like Chicago and Kansas City, it is of interest to compare the cost of delivering these cattle to New York with the cost of buying direct in Virginia and with the marketing costs of shippers located in that State who consign to the Jersey City market.

The freight rate on live cattle from Kansas City to Jersey City is 83 cents and from Chicago to Jersey City 56.5 cents per 100 pounds. Feeding costs en route approximate $7.50 per car between Kansas City and Jersey City and $4.50 per car from Chicago. Buying commission at both these midwestern markets is 50 cents per head, with a minimum of $10 and a maximum of $15 per car.

The New York slaughterer who buys cattle at Chicago or Kansas City must add the following charges per 100 pounds to his buying

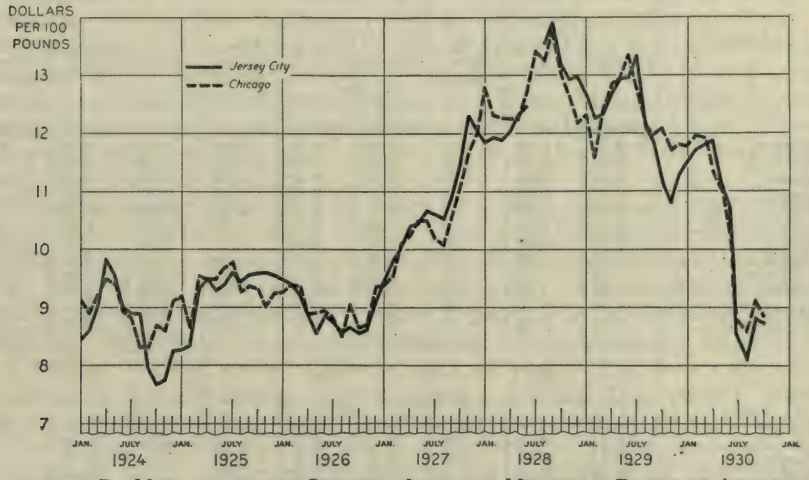

FIGURE 7.—MEDIUM-GRADE STEERS; AVERAGE MONTHLY PRICE AT JERSEY CITY AND CHICAGO, 1924–1930

Jersey City prices are usually higher than Chicago prices when heavy steers sell at a premium over lightweight steers. When the lighter steers command a premium over heavyweights Jersey City prices are usually lower than Chicago prices. This is particularly true in the late summer and fall and is important to Virginia cattle shippers because most of the Virginia steers are marketed as heavyweights

price to ascertain the approximate delivered cost to his plant on the basis of a 24,000-pound load of 20 steers:

If bought at Chicago:	Cents per 100 pounds	If bought at Kansas City:	Cents per 100 pounds
Buying commission	4. 2	Buying commission	4. 2
Freight	56. 5	Freight	83. 0
Feed in transit	1. 9	Feed in transit	3. 1
Total	62. 6	Total	90. 3

Apparently about 63 cents must be added to the Chicago purchase price and 90 cents to the Kansas City price to arrive at the cost laid down at the plant in Jersey City or New York. Knowing these costs and the prices prevailing at Chicago and Kansas City, together with the average yield and grade of beef that can be expected from western and Virginia cattle, the New York slaughterer can determine what he can afford to pay for Virginia cattle, either at the home of the producer

or at Jersey City. On cattle of similar grade and same yield of dressed beef, the Jersey City market must maintain a differential of not to exceed 63 cents above the Chicago price to be on a parity with the Chicago market. The required differential over Kansas City to put the two markets on an even basis is 90 cents. The actual price differentials between Jersey City and the western market are usually smaller than these figures. In fact, it is not uncommon for the quoted prices at Chicago to be higher than those quoted at Jersey City. (Table 17 and fig. 7.) The relationship between prices at Jersey City and at Chicago is discussed in detail later.

TABLE 17.—*Average price per 100 pounds of medium-grade steers, 1,100 pounds up, at Chicago and Jersey City and differential between the two markets, by months, 1924–1929*

Month	1924			1925			1926		
	Chicago	Jersey City	Price differential [1]	Chicago	Jersey City	Price differential [1]	Chicago	Jersey City	Price differential [1]
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
January	9.11	8.46	−0.65	9.20	8.26	−0.94	9.26	9.46	0.20
February	8.88	8.62	−.26	8.65	8.33	−.32	9.38	9.38	.00
March	9.22	9.04	−.18	9.54	9.32	−.22	9.37	9.22	−.15
April	9.47	9.84	.37	9.49	9.50	.01	8.88	8.85	−.03
May	9.39	9.56	.17	9.48	9.28	−.20	8.91	8.54	−.37
June	8.93	9.00	.07	9.69	9.38	−.31	8.95	8.87	−.08
July	8.80	8.90	.10	9.78	9.61	−.17	8.83	8.75	−.08
August	8.30	8.88	.58	9.26	9.44	.18	8.48	8.56	.08
September	8.29	7.96	−.33	9.36	9.56	.20	9.05	8.66	−.39
October	8.69	7.67	−1.02	9.32	9.58	.26	8.64	8.55	−.09
November	8.60	7.74	−.86	9.00	9.60	.60	8.71	8.62	−.09
December	9.11	8.24	−.87	9.24	9.55	.31	9.37	9.02	−.35
	1927			1928			1929		
January	9.39	9.46	0.07	12.81	11.85	−0.96	12.32	12.66	0.34
February	9.54	9.80	.26	12.32	11.93	−.39	11.58	12.24	.66
March	10.11	10.03	−.08	12.27	11.88	−.39	12.41	12.32	−.09
April	10.24	10.40	.16	12.24	12.02	−.22	12.86	12.69	−.17
May	10.50	10.44	−.06	12.22	12.32	.10	12.96	12.93	−.03
June	10.50	10.67	.17	12.72	12.45	−.27	13.36	12.96	−.40
July	10.19	10.62	.43	13.41			12.76	13.34	.58
August	10.08	10.53	.45	13.24	13.54	.30	12.17	12.08	−.09
September	10.59	10.94	.35	13.77	13.92	.15	11.98	11.86	−.12
October	11.09	11.48	.39	13.01	13.17	.16	12.10	11.16	−.94
November	11.67	12.30	.63	12.64	12.93	.29	11.73	10.82	−.91
December	12.00	12.03	.03	12.16	12.97	.81	11.80	11.30	−.50

[1] Jersey City price over Chicago price. Minus sign indicates that the price in Jersey City was lower than that in Chicago.

Packers who buy cattle direct from producers in Virginia and have them shipped to their plants pay an average of about 54 cents per 100 pounds for freight charges and feed in transit, and about 7 to 8 cents per 100 pounds as buying commission. As the net shrinkage of cattle consigned to Jersey City averaged around 4.7 per cent, allowance for this at the prevailing Jersey City market price must also be made in comparing the cost of buying in the country with the cost of buying on the market. If the current market price is $10 the cost of buying in the country would approximate $1.09 per 100 pounds and this amount would have to be subtracted from the Jersey City price to ascertain the price that the slaughterer could afford to pay in the country. This makes no allowance for possible loss or damage in transit, which under ordinary conditions is rather small.

COMPARISON OF CATTLE PRICES AT JERSEY CITY AND CHICAGO

At Jersey City it is the common practice to hold cattle on feed and water for 24 to 72 hours after arrival, the average as shown in Table 16 being about 38 to 40 hours. This permits cattle at Jersey City to take a very heavy fill as compared with those at Chicago. A heavy fill lowers the dressing percentage, and buyers take this into consideration when making bids. For instance, if the buyer has reason to believe that one steer carries 30 pounds more fill than another, he knows that the steer with the larger fill must be bought at a lower price if the dressed product from the two steers is to be equal in unit cost. Assuming a price of $12 per 100 pounds, 30 pounds of extra fill amounts to $3.60, and on a steer weighing 1,200 pounds, it would necessitate reducing the price 30 cents per 100 pounds to allow for this extra fill. In other words, making allowances for differences in fill could easily account for a difference of 20 to 40 cents per 100 pounds between prices at Chicago and Jersey City.

In addition to increased fill, buyers at Jersey City take into consideration certain physical characteristics frequently found in the cattle received at that market from Virginia and West Virginia which appear to be less common in cattle purchased at Corn Belt markets. These characteristics are discussed in that part of this bulletin that deals with the grade of Virginia cattle.

Another factor that must be taken into consideration when making price comparisons between Jersey City and Chicago is the opportunity of making a choice from a variety of offerings within the grade. The bulk of the steers offered for sale at Jersey City consists of rather heavy, aged steers, somewhat coarse in type, and in the summer and fall they are practically all grass finished. Such steers are in demand for only a certain class of trade, and as this demand is somewhat limited it can be easily oversupplied. During the period when receipts are largest at Jersey City, slaughterers have no great difficulty in supplying their needs for the plainer kinds of cattle, but they are compelled to go elsewhere to supply the remainder of their wants and about three-fourths of the time the Jersey City market offers little from which to choose.

At Chicago, a wide range of offerings within a grade are on sale the year around; young cattle and aged cattle, lightweights, medium weights and heavyweights, grass-fed and corn-fed. Slaughterers, knowing that a greater variety of offerings can be found at Chicago, prefer to buy there rather than to confine their purchases to a market that offers a limited supply and an equally limited range of grade, weight, and type. This preference is particularly marked when the difference in cost favors western markets. All this undoubtedly tends to reduce the buying competition between slaughterers at Jersey City. Another type of competition absent from that market is that which comes from the stocker and feeder buyer. Practically all of the offerings at Jersey City go direct to slaughterers, as it is seldom that any are taken back to the country.

Table 17 shows that in 1924 Jersey City prices were higher than those at Chicago from April to August, inclusive, and considerably lower during January and during the last three months of the year. In 1925, Chicago prices were higher than those at Jersey City during the first seven months with the exception of April. Excluding January, the differentials were not large. During the last five months, Jersey City prices exceeded Chicago prices by a fair margin.

The price differentials in 1926 were relatively small throughout the year, but in only two months, January and August, were Jersey City prices higher than those at Chicago. In 1927 Jersey City prices exceeded Chicago prices in every month except March and May. In 1928 they were higher than Chicago prices in May, and from August to December, inclusive. During 1929 they were lower than Chicago prices in all months except January, February, and July.

In three years out of the six, Jersey City prices were higher than those at Chicago during the months when receipts were largest, which is the period during which the bulk of the Virginia cattle are marketed. The most striking feature revealed in comparing prices at the two markets is that when heavy cattle were selling at a premium over lightweights, prices at Jersey City were higher than those at Chicago, and when the situation was reversed (when lightweights commanded the premium) Chicago prices were the higher of the two. Since the bulk of the steer receipts at Jersey City comprise heavyweights, especially those originating in Virginia, this is a matter of significant importance to Virginia cattle producers. In brief it means that when weight is in demand, slaughterers may be willing to put less emphasis on grade in order to get the heavy cattle needed; and at such times Virginia cattle usually sell well.

On the basis of weekly average prices at the two markets, it is found that in the 309 weeks for which prices are available in the six years, 1924–1929, there were 165 weeks when the Chicago price exceeded the Jersey City price, 139 weeks when the Jersey City price was the higher of the two, and 5 weeks when the average prices were the same. The average of the differential in the 165 weeks when the Chicago price exceeded that at Jersey City amounted to 38.6 cents, and in the 139 weeks when the Jersey City price was highest it amounted to 32.7 cents.

It is apparent, therefore, that over a long period the averages of the two differentials tend to equal or to cancel one another. In other words, in averaging the differential for the 309 weeks it is reduced to about 6 cents in favor of the Chicago price. With free trading and ordinary competitive conditions, it may be assumed that over a long period prices at the two markets have tended to adjust themselves to an equal basis, due allowance being made for the factors that must be given consideration by the buyer. These factors are the cost of transporting cattle from Chicago to Jersey City as one element which is offset by such unfavorable items in Jersey City offerings as excessive fill, lack of variety in grade and weight from which to make selections, and undesirable characteristics which tend to make the meat difficult to sell in a discriminating market like New York.

MARKET GRADES OF CATTLE

In the wholesale-beef trade there are four principal commercial grades of beef. These, in descending order are, Choice or No. 1, Good or No. 2, Medium or No. 3, and Common or No. 4. Corresponding grades are found in the live-cattle market. Grades lower than Common are known as Cutters or No. 5, and Low Cutters or No. 6, but these are found only in limited numbers in steers of any degree of beef breeding and then only when the animals are extremely thin from lack of sufficient feeding or because of disorders. The very highest grade of steers is known as Prime or No. A1, but those of this grade are usually so nearly ideal in conformation, quality, and finish

as to make them suitable for show purposes. Because of their relative scarcity they are not very important in the commercial supply.

The proportion of the different grades in the market supply varies from year to year and rather widely according to season. This is because the degree of finish or fatness is one of the important factors in determining the grade of a steer, and feeding and grazing practices are regulated to a large extent by the seasons. Other things being equal, cattle fattened on grass grade lower than do those fed extensively on grains and other concentrates, and, excluding those produced in southern Texas, most grass cattle are marketed in the late summer and fall near the end of the grazing season. The feeding of cattle on grain begins after the grain crops are harvested and extends through the following winter and spring and to a limited extent into the summer. Steers that have been on grain for a limited period (30 to 90 days), are frequently referred to as "warmed up" and "short-fed" steers. Those fed grain four months or longer are commonly spoken of as "long-fed." Cattle fattened on grass are known as "grassers."

As a result of the grazing and feeding practices followed in this country the market supply of cattle tends to vary in make-up and quality through the year as follows:

January—Mostly "warmed-up" and "short-fed" steers and heifers grading Common and Medium to low Good, with some fed cows.

February.—Much like January but with a larger proportion grading higher because of longer feeding on grain.

March.—Steers predominate, with a larger proportion in the higher grades than in the two previous months because of the longer time on grain feed. Cows coming to market are largely from dairy herds.

April.—"Long-fed" steers and yearlings more numerous and "short-feds" less plentiful. Cows largely from dairy herds. Because of their relative scarcity Common and Medium grade cattle sell near the levels of the better grades.

May–June.—The better grades of fed steers are relatively most plentiful and the Common and Medium grades scarcest. As a result, the spread between the lowest and highest prices is the narrowest for the year. Some grass cattle from southern Texas begin to appear in market receipts.

July–August.—Grass cattle increase in numbers as the season advances, and "grain-feds" are less plentiful, although the actual number of "long-feds" grading Choice and better increases. The supply of cows also increases. The price spread on steers widens as prices of the better grades advance and those of the lower grades decline.

September–October.—Grass cattle make up the bulk of the supply, and grain-feds are relatively scarce. The price spread continues to widen and usually reaches its maximum in one of these months. Grass cows from beef herds make up a larger proportion of the supply.

November.—November is the clean-up month, and the supply includes a large proportion of low-grade cattle of various kinds which producers deem inadvisable to carry through the winter. Near the end of the month the supply includes a number of "long-fed" cattle that were fattened for exhibition at the livestock shows and expositions and for the holiday market.

December.—Many "warmed-up" cattle in the supply and a few "long-feds" for the Christmas beef market.

An unpublished study made by the Bureau of Agricultural Economics in 1920 indicated that the percentage distribution of the different grades of steers slaughtered during the war period and the postwar period up to 1920, inclusive, was approximately as follows: Prime, 0.5; Choice, 4; Good, 22; Medium, 53; Common, 17; and Cutter and Low Cutter, 3.5. The precentage distribution varies widely between markets, however, and some markets seldom, if ever, receive any Choice and Prime steers for sale, and their offerings of Good grade steers are usually very limited in number.

The bulk of the Choice and Prime steers are produced in the Corn Belt States, and a very large portion of these steers are marketed at Chicago. For this reason the average quality of the Chicago receipts is much higher than that at other markets. Table 18 shows the average monthly percentage distribution of steers by grade (western range steers excluded), sold out of first hands for slaughter at Chicago for the eight years 1922–1929. Since steers from the western ranges were omitted from the data from which these percentages were computed this table does not give a complete picture of the total supply situation. If western steers were included the figures would show that the majority of the steers marketed for slaughter are of Common and Medium grades. These two grades include practically all cattle that have been finished on grass and a large part of those that have been fed for a short time on grain and other concentrates. It is apparent, therefore, why they comprise the bulk of the market offerings. A few of the best grass cattle will grade in the low end of Good, but the majority will not grade higher than Medium.

TABLE 18.—*Percentage distribution of steers sold out of first hands at Chicago, by grade and by month, average, 1922–1929* [1]

Month	Choice and Prime	Good	Medium	Common	Other grades
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
January	2.8	19.9	50.3	24.2	2.8
February	3.2	20.9	52.7	21.3	1.9
March	4.2	24.5	49.4	19.8	2.0
April	8.4	28.2	47.4	14.2	1.8
May	9.6	34.0	43.2	11.4	1.9
June	17.2	38.7	34.1	7.6	2.4
July	20.9	38.9	29.1	8.4	2.7
August	18.8	44.4	26.5	8.4	1.9
September	14.9	45.1	25.2	12.4	2.4
October	15.9	37.3	27.1	16.6	3.1
November	9.8	30.6	36.8	19.7	3.1
December	5.7	24.2	44.4	23.1	2.6
Average	11.0	32.3	38.9	15.4	2.4

[1] Western range steers excluded.

To grade Choice or Prime, cattle must have been fed extensively on grain or other concentrates, and most cattle of Good grade will have received considerable concentrates. The fact that grass-fat steers are marketed during the latter half of the year and comprise the bulk of market receipts of steers during September, October, and November obviously increase the proportion of Medium grade steer beef at this season to the highest levels of the year. Likewise the supply of the higher grades, Good and Choice, declines during these months. This condition results in the extremely wide price spread between the different grades of both slaughter steers and dressed beef during the fall months. This is brought out in Figure 8, which shows the monthly average prices of western dressed fresh steer beef at New York, and in Figure 5, which shows the average prices of the different grades of beef steers sold out of first hands at Chicago for slaughter. With a large supply of Medium and Common grades, the prices for such grades are forced down, while a relative scarcity of the higher grades tends to hold or advance the values of these. During the spring and early summer months the opposite condition prevails, as the supply of cattle fed extensively on grain and other

concentrates is the largest of the year, the number of low grade cattle is the smallest, and the price spread is contracted.

Virginia cattle that have been fattened on grass, although varying somewhat, will mostly grade Medium. Of the 52 shipments followed through the market from southwest Virginia, 85 per cent graded from average Medium to low Good. The other 15 per cent graded down to the low end of Medium, with a few individual steers grading as low as Common. A similar range in grade was noted in the beef produced from these steers. The cattle from north Virginia graded slightly higher than those from the southwest section, only about two lots grading below average Medium and about 90 per cent from average Medium to average Good.

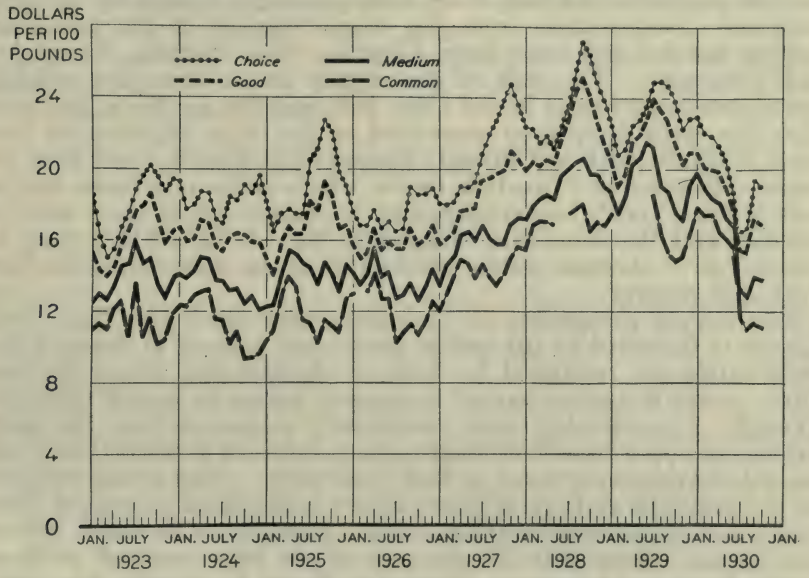

FIGURE 8.—WHOLESALE PRICES OF WESTERN DRESSED FRESH STEER BEEF AT NEW YORK CITY BY GRADES, 1923 TO OCTOBER, 1930

The lower grades of beef are scarcest and sell at the highest prices from late winter to early summer. They are the most plentiful and sell at the lowest prices in the fall and early winter. The reverse is generally true of the better grades

COMPETITION FOR VIRGINIA BEEF IN THE NEW YORK MARKET

Since the ultimate destination of a large percentage of the beef cattle produced in Virginia is the metropolitan district embracing New York City and surrounding towns, the demands of that market and the source of its beef supplies should be given consideration by Virginia cattle producers.

New York City is the distributive center for a population of approximately 10,000,000 people; hence it requires immense quantities of foodstuffs daily. Concentrated in this congested area is the greatest buying power in the United States, if not in the world. In degree of wealth the consumers who must be supplied range from those living in extreme poverty to those who can buy the most expensive luxuries. Nowhere is a greater variety of food products offered for sale; nowhere is greater and less discrimination shown with respect to quality in the purchase of food; hence in no other city is one likely to find a wider range in food prices.

New York's tremendous consuming capacity makes it a dominating factor in determining prices for food products throughout the country. Particularly is this true in the case of meats, and consequently of livestock. Price changes in New York's wholesale meat markets are quickly reflected in the livestock markets throughout the country; hence livestock and meat-trade interests in every important center usually keep in close touch with developments in New York City.

Available records show that the meat supplies of the New York metropolitan district in 1928 totaled almost 1,500,000,000 pounds, of which more than 600,000,000 pounds, or 44 per cent, was beef. Only a very small part of this beef is produced in near-by territory, and that is mostly from dairy cows which have ceased to be profitable as milk producers and from dairy bulls no longer desired for breeding purposes. Some comes from the steers fattened in the Lancaster feeding district and some from Virginia, West Virginia, Kentucky, and Tennessee. The bulk of the supply comes from the surplus-cattle-producing States in the Corn Belt and the far West, but only after the cattle have been assembled at the large mid-western livestock markets, such as Chicago, Kansas City, Omaha, and East St. Louis. Western or Corn-Belt cattle, which ultimately make up the bulk of New York's beef supply, may be slaughtered at these western markets and the meat then shipped to New York, or they may be shipped alive through public stockyards to be slaughtered in New York and vicinity.

The largest proportion of the cattle that reach the New York district is unloaded at the public stockyards located in Jersey City. Such cattle are reshipped by boat to slaughtering plants in New York, or are driven or hauled to near-by plants in Jersey City and Newark. Considerable stock, particularly shipments from the dairy sections of upper New York State, also is received at the public yards located at Forty-first Street in New York City. Open public markets for the purchase and sale of livestock are maintained at both of these yards, and considerable trading is done, particularly in cattle, calves, and lambs. More than 98 per cent of the hogs received at these yards, however, represent shipments direct to slaughterers from points in the Corn Belt. The bulk of the livestock received for sale represents the receipts from near-by States and from Virginia, West Virginia, Kentucky, Tennessee, and Ohio.

Beef from cattle slaughtered at the western packing centers is shipped in refrigerator cars and is known as western-dressed beef. Most of this beef is shipped as carcasses divided into quarters.

Beef from animals slaughtered in the local slaughterhouses in New York and vicinity is known in the trade as city-dressed or locally dressed beef. Although it would seem uneconomical to ship live cattle such great distances as from Chicago and Kansas City to New York for slaughter when fresh beef can be transported in good condition in refrigerator cars, more than one-half of New York's beef supply is obtained from this source. Local slaughter of cattle is necessary in order to meet the requirements of New York's large Jewish population.

The religion of the orthodox Jews prohibits those of that faith from eating pork in any form, and requires that their beef, veal, lamb, and mutton come from the fore quarters of animals slaughtered in a prescribed manner; the meat should be used within three days after

slaughter. Such meat is known as kosher meat. Kosher is a Jewish word meaning ceremoniously clean. If fresh kosher meat is not used within three days after slaughter it must be washed every third day thereafter until the twelfth day, after which it is no longer considered kosher but is referred to as "tref," meaning ceremoniously unclean and may not be used. Very little fresh meat is used as kosher after the third day unless a holiday or some emergency makes it seem necessary. The hind quarters from kosher cattle and sheep are sold to the non-Jewish trade.

The quantities of the various kinds of beef available in New York in the three years, 1927–1929, are shown in Table 19. New York takes about 10 per cent of the country's total federally inspected slaughter of cattle, exclusive of calves. Prior to 1927 it used on the average nearly 1,000,000 cattle annually, excluding calves, but during the last four years the consumption has dropped below this amount chiefly because of the general reduction in cattle slaughter due to decreased production.

TABLE 19.—*Supplies* [1] *of beef in metropolitan New York, 1927–1929*

Kind of beef	Estimated average weight	1927 [1]	1928 [1]	1929
Western dressed:	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Steer carcasses	600	[1] 242,519,700	[1] 207,039,150	[1] 237,103,800
Cow carcasses	500	[1] 15,903,000	[1] 19,372,000	[1] 20,585,750
Bull carcasses	700	[1] 3,660,300	[1] 3,931,900	[1] 3,495,450
Beef cuts		21,811,245	16,578,647	18,628,528
Beef offal		1,100,520	1,176,123	1,231,918
Beef trimmings		22,955	80,179	229,569
Cured beef		264,957	250,850	195,496
Total		285,282,677	248,428,849	281,470,511
Locally dressed:				
Steer carcasses	750	[1] 315,165,000	[1] 292,890,000	[1] 289,175,250
Cow carcasses	475	[1] 12,722,875	[1] 19,783,275	[1] 13,706,125
Bull carcasses	700	[1] 29,113,000	[1] 32,146,800	[1] 25,425,400
Total		357,000,875	344,820,075	328,306,775
Imports:				
Beef carcasses	600	[1] 6,496,200	[1] 24,112,500	[1] 10,030,050
Beef cuts		837,097	3,708,853	4,085,509
Cured beef		141,551	347,509	2,426,934
Canned meats [2]		13,661,468	8,611,881	22,803,674
Total		21,136,316	36,780,743	39,346,167
Grand total		663,419,868	630,029,667	649,123,453

[1] The total weight of carcass beef was computed by multiplying the actual number of carcasses by estimated carcass weights.
[2] This is believed to be mostly beef.

The outstanding characteristic of New York's beef consumption is the marked preference for steer beef. Approximately 18 to 20 per cent of the total federally inspected slaughter of steers goes into New York's fresh beef supply whereas less than 2 per cent of the inspected slaughter of cows and heifers is included in this supply. In other words, New York uses almost 13 pounds of fresh steer beef to 1 pound of fresh cow and heifer beef. It also uses about 12 to 16 per cent of the annual inspected slaughter of bulls and stags.

The kosher trade prefers heavy steer beef but will also pay top prices for well-finished yearling beef. The average weight of locally dressed

steer carcasses is much greater than that of western-dressed steers being estimated at 750 pounds as compared with 600 pounds for the latter.

The hotel and steamship trade also prefers heavy beef and uses the hindquarters from koshered cattle. There is also a demand at Boston for some of the heavy beef that reaches New York.

Average weekly supply figures for the five years 1924–1928, inclusive, show that New York's beef supply is fairly steady throughout the year. Supplies tend to decline slightly from the beginning of the year until about the first of April, probably because of reduced demand during the Lenten season, which extends from about the middle of February to Easter. Supplies then increase until about the middle of May, at which time there is a strong demand for kosher beef following the Jewish Passover, which occurs usually in April. From the middle of May until about the first of August supplies decrease, probably because the demand is decreased by the gradual rise in temperature as summer weather approaches and by the departure of many people from the city on vacations. New York has many visitors during the summer, however, and there is a tendency for supplies to increase during August and to decline sharply about the first week in September, when the Labor Day holiday occurs. Supplies again increase during September and October, to meet the increased demand resulting from the return of those who have been away from town, but they fall off during the end of the year, at the time of the Thanksgiving and Christmas holidays.

Demand for locally dressed beef is affected materially at the time of Yom Kippur, which usually occurs in September or early October. This is a period of fasting for orthodox Jews, and no meat is eaten by them then; hence smaller supplies are required. The fact that Yom Kippur occurs during the time when cattle are moving freely to market from Virginia is an adverse factor in the marketing of these cattle, and experienced Virginia shippers endeavor to avoid having their cattle reach market during this holiday.

The hind quarters from koshered cattle are sold to the non-Jewish trade, and if the supply is unusually large the market may not absorb it except at a discount, as the average non-Jewish consumer prefers beef from cattle of lighter weight than those used in the kosher trade. The best outlet for such hind quarters is the trade from hotels, restaurants, dining cars, and steamship companies, but this trade prefers the Good and Choice grades, which are not produced to any great extent in Virginia. This tends to restrict the outlet for the hind-quarter beef from Virginia cattle even though there might be a good demand for the fore quarters. This undoubtedly is one of the factors which frequently adversely affects the price of Virginia cattle.

The fact that Virginia cattle are finished on grass and are marketed in the late summer and fall, which is the time when grass cattle are most abundant, undoubtedly makes it difficult to realize the best returns on them and is a matter that the producers of such cattle should consider. Furthermore, the growing tendency in the Middle West to finish cattle on corn or other concentrates, and the increasing demand for more highly finished beef on the part of consumers, is tending to develop stronger competition against all grass cattle. Most of the strictly grass-finished beef of western origin is from lighter and younger animals than the beef from Virginia steers. The bone is not

so hard, and the meat is likely to be slightly more tender. It should be kept in mind, however, that although the beef from Virginia steers might grade the same as that from western grass steers it would not necessarily sell at the same price. Weight is a factor of considerable importance in the New York market; for this reason strictly grass-finished beef from Virginia steers usually will command a higher price than that from the lighter-weight western grass steers even though the grade may be the same.

In making price comparisons with cattle sold or bought at mid-western markets the Virginia producer is more likely to compare his cattle with grain-fed steers from the Corn Belt rather than with the grass cattle of that region or the West. Seldom will he find that his grass-fed steers sell as low as the bulk of the strictly grass-fed steers of the range country, but neither is he likely to find that they sell as high as Corn Belt steers that have had considerable grain.

PROBLEM OF DARK-COLORED BEEF

Carcasses from Virginia steers vary considerably in their visible characteristics and these variations account in large degree for differences in grade. Some characteristics frequently noted in the carcasses of these steers are considered objectionable by meat dealers, particularly those in New York City. These are as follows:

Conformation.—Rounds poorly developed, loins flat or slightly concaved, fores "spready" with ribs lacking in high degree of plumpness, chucks slightly angular and rough.

Finish and quality.—Flesh lacking firmness; liberal covering of fat on exterior but uneven in distribution; moderate fat deposits over kidneys and in other internal sections; fat yellowish-white rather than the desired creamy-white color, and inclined to be soft. Lean meat shows little evidence of marbling and is dark-red instead of the preferred light, or cherry, red color. Bones hard and flinty.

Beef that shows the above-mentioned characteristics practically always grades Medium or lower. Contrast these characteristics with the following which are usually noted in Virginia beef that will grade Good.

Conformation.—Rounds and loins well developed; fores and ribs fairly blocky.

Finish and quality.—Flesh fairly firm to firm and smoothly covered with a moderate quantity of creamy-white fat; normal quantity of fat over kidney and other internal sections; lean is light red and possesses a fair degree of marbling; chine bones are moderately soft and show considerable redness and cartilaginous ends.

When using Virginia beef in their trade New York dealers frequently attempt to substitute it for beef from grain-fed steers that have been slaughtered locally. Excluding those finished on grass in Virginia and West Virginia, the bulk of the steers that go into the kosher trade in New York comprise grain-fed steers from the Corn Belt which yield carcasses weighing from 750 pounds up; the hindquarters and ribs from these steers enter largely into the hotel, restaurant, steamship, and dining-car trade. Grass-finished steers from Virginia and West Virginia usually are heavy enough to yield carcasses of the desired weight for this trade, and the best of these carcasses possess fairly good conformation and usually have a fair covering of fat. But the meat is frequently dark red rather than a light red, or cherry, color. In a total of 1,098 carcasses from the steers shipped from southwest Virginia in the summer and fall of 1924, and followed through the slaughter plants and meat coolers, it was found that 269,

or 24.5 per cent, were dark in color. Of the steers shipped from the Shenandoah Valley and north Virginia which had received some grain only 7.3 per cent cut dark.

In referring to beef that is dark red in color the trade often uses the terms "black" and "dark." The trade also uses the terms "black cutter" and "dark cutter" in referring to carcasses that have flesh that is darker in color than is desired.

When the hind quarters and ribs of Virginia steers are sold as substitutes for grain-fed beef they are likely to bring complaints from customers. This is particularly true if there are dark cutters among them. Customers who are accustomed to buying grain-fed beef that is of brighter color are not satisfied with the dark-cutting meat.

The first lot of hind quarters and ribs a wholesaler buys may look like a profitable investment, but when he gets complaints from his customers he promises himself that he will never buy any more beef from Virginia steers. The facts in the case are that the meat is not sold for what it is; it is sold as a substitute for something better but at nearly the same price. In some instances lots of Virginia beef are mixed with grain-fed beef of western origin in the coolers of local slaughter plants. Some buyers detect them and reject them when buying. Others take some of the carcasses without knowing it until the carcasses are cut up in their places of business, after which they complain and ask for adjustment. Some slaughterers sell hind quarters and ribs with a guarantee that they will cut bright. They have to credit back those that cut dark; this prejudices them against this type of beef because it can not be depended upon for color. Some slaughterers sell "as is" and then the buyer must beware, but if he finds a lot cutting out in an unsatisfactory way he is bitter against the Virginia beef for some time.

There is probably just as large a percentage of dark-cutting carcasses from cattle from western ranges as there is among Virginia steers, but the western grass-fed beef is not sold in competition with grain-fed beef. It usually sells at a lower price and on the whole escapes the complaints that are so often applied to the beef from Virginia. When the New York slaughterer speaks of western beef and compares it with that from Virginia cattle he always has in mind steers that have been fed some grain and usually those that have had considerable grain. He never intentionally buys strictly grass-fed beef from the West unless it is exceptionally good. As a consequence when he is comparing Virginia beef with western beef he is seldom making a comparison between cattle produced under anything like similar conditions. He figures the returns he gets from each load. If the Virginia cattle make money for him but cause him trouble in selling them, he may consider that his profits have reimbursed him for his troubles; but if he loses money on the transaction, or makes less than other dealers and, in addition, has trouble with his trade, he becomes a very poor customer for future offerings.

TRADE OPINION REGARDING VIRGINIA CATTLE

To ascertain the attitude of the trade toward the beef from Virginia and West Virginia steers, several of the leading wholesale beef distributors in New York City were interviewed and asked to com-

ment on the relative differences in the beef from these cattle and that from cattle produced and fed in the Corn Belt. These comments, although naturally varying somewhat in form of expression, were practically unanimous in their general meaning. It should be remembered that they represent individual opinion based on trade experience in buying and selling beef rather than on scientific research. They are presented here primarily for the purpose of showing the trade viewpoint.

It was apparent that in making comparisons the wholesalers usually had in mind corn-fed steers rather than western grass steers when referring to western or native cattle. This was well illustrated in the rather common statement that there was no comparison between the two classes of cattle, or that they could not be compared. The statement of the manager of the beef-sales department of one of the larger firms represents about the general opinion expressed by the New York dealers. His statement was as follows:

A Chicago native steer carcass usually has well-shaped, smooth hind quarters of uniform thickness, and small compact fore quarters. The bone is inclined to be soft; the fat is evenly distributed throughout, and is usually white in color. The carcass yield ranges from 58 to 61 per cent of the live weight. A large percentage of such cattle will grade from Good to Prime, and only a few will be coarse. The meat from these cattle has a bright and attractive appearance. Virginia cattle, on the other hand usually have flatter rounds, more sunken loins and proportionately large fore quarters. They have harder bone and such fat as is carried is usually on the outside and is yellowish in color. They yield, according to quality, from 55 to 57.5 per cent carcass. The meat is likely to be coarse and rather dark in color as compared with the meat from grain-fed steers. One superior characteristic of Virginia cattle is that they yield a larger percentage of clear, spready hides than do Chicago cattle, the hides of which are often branded. The difference between clear, spready hides and branded hides, is from 3 to 5 cents per pound in favor of the clear hide, depending on the price level for hides. Comparing carcasses of Virginia grass cattle with those from the better grades of western grass cattle, the latter usually have better conformation and more meat in proportion to bone. The meat also seems to be superior in quality, usually is brighter in color, and is more salable.

Another dealer stated:

If southwest Virginia cattle of equal quality were fattened on corn and fed to the same degree of finish as is found in the corn-fed cattle bought at Chicago, they would be just as desirable for New York slaughter as the Chicago cattle. Being grass-fed, cattle from southwest Virginia should be compared with cattle handled and fed or grazed in like manner. The grass cattle from Kentucky are more nearly comparable with those produced in Virginia. Ripe, corn-fed cattle when ribbed, will cut bright, meaning that the meat is of a bright-red color. In addition to cutting bright, the meat is nicely mixed with fat, which insures the eating qualities so generally desired. Grass-fed cattle, regardless of where they come from, are likely to show a larger percentage cutting dark than do corn-fed cattle, but we find that Virginia grass-fed cattle show a larger percentage of "blacks" than grass-fed cattle from other sections.

In the opinion of the trade, the wholesale price differentials between bright-cutting and dark-cutting carcasses varied from 1 to 10 cents per pound, depending upon the general price level and the demand for beef. The majority of those questioned stated that the average differential would vary from 3 to 5 cents.

The general opinion of those who slaughtered cattle was that it was impossible to determine before slaughter which animals would yield dark-colored beef. One dealer thought that lack of finish was the best indication, but he also stated that even the best grain-fed steers would sometimes cut black and that unfinished cattle would often yield bright meat. Another dealer was of the opinion that a larger

percentage of dark cutters would be obtained during the years when the grass was watery or "slushy" as a result of too much rain. It seems possible that there may be some foundation for his contention, as reports indicated a smaller proportion of dark cutters in 1925, when pastures were dry, than in 1924, when there was more rain and the grass was more watery. Two dealers suggested that the manner of handling the cattle immediately prior to slaughtering might have some influence on the color of the meat. They thought that if the cattle were allowed to rest for 36 to 48 hours before slaughter and given an opportunity to quiet down, the percentage of dark cutters would be greatly reduced.

In regard to the time of the year when dark cutters were likely to be most prevalent, the general opinion seemed to be that it was in late summer and fall, which coincides with the time of marketing grass cattle and hence is not indicative of anything other than that dark cutters are probably more common among grass cattle than among those fed grain. Some of the dealers stated that a small percentage of dark cutters are found throughout the year in grain-fed cattle.

Although opinion was somewhat divided as to whether the age of the cattle was a factor in determining the percentage of dark cutters, the majority indicated that this condition was found most commonly in aged steers, or those 4 years old or over. As most of the Virginia cattle are marketed and slaughtered as aged steers, no definite conclusion regarding this point can be drawn from the evidence available. The fact that one of the prize-winning baby beeves raised by a member of a boys' beef club in Virginia in 1924, dressed out dark beef, indicated that age may not be a cause. Several slaughterers stated that they had found dark cutters in cattle of all ages, ranging from yearlings to the oldest reaching the market. Most of them stated that black or dark-cutting were carcasses more commonly obtained from steers than from cows and heifers. This may be due to the fact that the number of females slaughtered is relatively small. Most of the slaughters also stated that black cutters were found occasionally in all grades as both the best and the poorest might cut dark. The keeping qualities of dark beef seemed to be as good as the bright colored, although its unattractive appearance made it difficult to sell to discriminating customers. So far as can be determined dark color does not affect the palatability of the meat and usually disappears in the process of cooking.

POSSIBILITIES OF INCREASING RETURNS ON VIRGINIA STEERS BY IMPROVING THE GRADE

Since Virginia cattle are fattened largely on grass they are marketed at a time when supplies of similar grades are most abundant and the price for such grades is least favorable. It is apparent, therefore, that anything that could be done toward changing the time of marketing or improving the grade of these cattle without involving too large additional cost probably would result in increased net returns to the Virginia producers. Although the marketing season can be advanced to a limited extent, thus obtaining slightly higher returns on the earlier shipments and reducing the volume of marketings during the peak period, the possibilities here are limited because the Virginia cattle grazier wants to obtain the maximum utilization of his pastures and have his steers make the largest possible gain in weight.

He can accomplish these only by keeping his cattle on grass until near the end of the grazing season in the fall.

Possibilities of improving the grade and selling value of Virginia cattle by supplementing pastures with grain and other concentrates during the grazing season deserve consideration. Experiments in cattle feeding conducted by the Bureau of Animal Industry and the West Virginia Experiment Station in Greenbrier County, W. Va.,[3] where conditions are similar to those in southwest Virginia, indicate that net returns can be increased materially in this way.

These feeding experiments were conducted in the three years, 1926 to 1928, inclusive; the tests were made with two grades of feeder steers, Medium and Good. The average weight of the steers at the beginning of the experiment for the three years was 918 pounds for the Medium grade and 966 pounds for those grading Good. The purchase price of the latter kind was $1.25 per 100 pounds greater than the price paid for the Medium steers.

The steers were bought in December and wintered in the usual way on corn silage, wheat straw, and cottonseed meal, and they were given access to pasture that was somewhat better than the average. The two grades were fed as near alike as possible, but the Good grade steers, being heavier and larger, consumed slightly more feed than did the Medium steers. The rations were sufficient to permit some gain in weight. In an average winter-feeding period of 140 days for the 3-year experiment, the Good grade steers gained 78 pounds per head in weight as compared with 59 pounds for the Medium steers, the Good grade steers making greater gains in proportion to the feed consumed than the Medium steers.

When the steers were turned on grass in late April each grade lot was divided into two lots. One lot of each grade was given access to pasture without supplementary feed, and the other two lots were fed a supplement of coarsely ground shelled corn and cottonseed meal. An average of the summer gains for the three years shows that the Good grade steers fed grain gained 317 pounds as compared with 337 pounds for the Medium steers handled in a similar way. The average increased gain of the Medium steers over the Good grade in these lots amounted to 6.3 per cent for the 3-year period.

The Good grade steers on grass alone made an average summer gain of 228 pounds as compared with 249 pounds for the Medium steers on grass without supplements. The average increase in gain for the Medium grade over the Good grade in these lots amounted to 9 per cent.

A supplement of corn and cottonseed meal increased the daily gains 54 per cent the first year (1926), 22 per cent the second year, and 40 per cent the third year, making an average of 37 per cent for the three years.

The profits during these three years were increased 29 per cent, 18 per cent, and 19 per cent, respectively, or an average of 20 per cent for the 3-year period, by the feeding of a supplement to steers on grass.

The feeding of grain increased the selling price of the Good grade steers $1.24, or 10 per cent, and the Medium grade steers $1.22, or 11 per cent.

[3] Black, W. H., Warner, K. F., and Wilson, C. V. BEEF PRODUCTION AND QUALITY AS AFFECTED BY GRADE OF STEER AND FEEDING GRAIN SUPPLEMENT ON GRASS. U. S. Dept. of Agr. Tech. Bul. 217, 44 p., illus. 1931.

In 1926, the first year of the experiment, cattle prices were comparatively low and feeding was generally unprofitable, yet supplementing pasture with corn and cottonseed meal increased the net returns almost $5 a head on Good grade steers and $7.50 on Medium steers. In 1927 and 1928, the general cattle-price level advanced sharply, and this increased profits on all cattle-grazing and feeding operations. In these years, however, the use of supplementary feeds with pasture resulted in increases in the net returns ranging from about $8 to $17.50 per head over those obtained by the use of pasture alone.

Since the increase in profits was due to the higher selling price as a result of improving the quality and finish of the steer by the use of grain as well as of obtaining increased gain in weight, the cattle producer should give consideration to the probable margin that might be expected between the prices of different grades of steers at different seasons of the year. Table 20 shows the margins between average monthly prices of Good and Medium steers at Chicago for the nine years, 1921–1929, and Table 21 shows similar data for Jersey City for the six years, 1924–1929, as far as available. Good grade steers are not always on sale on the Jersey City market in sufficient numbers to warrant quotations, and when on sale they seldom represent the full range of the grade.

TABLE 20.—*Margin between average prices per 100 pounds of Good and Medium steers at Chicago, by months, 1921-1929*

Month	1921	1922	1923	1924	1925	1926	1927	1928	1929	Average 1921–1929
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
January	0.95	1.03	1.64	1.34	1.89	1.19	1.49	3.15	1.75	1.60
February	.70	.93	1.02	1.56	1.90	1.03	1.50	2.80	1.47	1.43
March	.71	.76	.81	1.60	1.22	.90	1.36	1.81	.72	1.10
April	.50	.60	.77	1.66	1.02	.83	1.47	1.50	.90	1.03
May	.54	.48	.74	1.37	.97	.72	1.44	1.37	.86	.94
June	.48	.60	1.07	1.18	1.12	.75	1.55	1.12	1.08	.99
July	.70	.82	1.12	1.34	2.25	.81	2.48	1.58	2.18	1.48
August	1.25	1.03	2.56	1.62	3.06	1.06	2.46	1.92	2.46	1.94
September	1.37	1.42	1.96	1.63	2.28	1.21	2.95	2.34	2.31	1.94
October	1.60	1.96	1.63	1.51	3.35	1.70	3.39	2.50	2.00	2.18
November	1.54	2.34	1.59	1.69	2.34	1.75	3.81	2.41	1.55	2.11
December	1.29	2.07	1.54	2.01	1.42	1.51	3.44	2.28	1.63	1.91

TABLE 21.—*Margin between average prices per 100 pounds of Good and Medium steers at Jersey City, by months, 1924-1929*

Month	1924	1925	1926	1927	1928	1929	Average [1] 1924–1929
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
January	1.95	1.36	----------	0.79	2.21	1.34	1.53
February	1.85	1.41	----------	.83	2.22	----------	1.58
March	1.74	[2] 1.36	1.16	.82	1.80	1.06	1.32
April	1.73	1.34	1.17	.86	1.47	1.14	1.28
May	1.57	1.14	1.10	.80	1.26	1.14	1.17
June	1.34	1.14	1.09	1.02	1.34	1.13	1.18
July	1.22	1.69	1.15	1.50	----------	1.40	1.39
August	1.25	2.19	1.28	1.48	1.78	1.85	1.64
September	1.96	1.88	1.26	1.87	1.58	1.67	1.70
October	----------	2.24	----------	1.88	.85	1.59	1.64
November	----------	1.62	----------	2.31	1.19	1.61	1.68
December	1.62	----------	.68	2.41	----------	1.54	1.56

[1] Average of the years for which quotations were available.

[2] Beginning Mar. 7, 1925.

Table 20 shows that in the four months when the bulk of the Virginia steers are marketed, August to November, inclusive, Good grade steers at Chicago sold on the average about $2 per 100 pounds above the price of Medium grade steers. Table 21 shows that at Jersey City the average margin in the same months ranged from $1.64 to $1.70 even though the full range of Good grade was not quoted on that market. These facts indicate that Virginia cattle producers might well give consideration to the use of supplementary feeds in connection with fattening steers on pasture, even though such feeds cost more in Virginia than they do in the Corn Belt. The use of better breeding stock and supplementing pastures with grain and other concentrates will make it possible for the Virginia cattle producer not only to market Good, and possibly Choice, steers rather than Medium grades as is now being done, but also to produce more nearly what the consumer demands and increase his chances for profit.

CONCLUSIONS AND RECOMMENDATIONS

All the information obtained on the shipments followed to market indicates that the market returns reflect the inherent characteristics of the cattle. Most of the Virginia cattle conform to the old English type first brought to this country, being rough in appearance and lacking desired beef conformation. They are slow to mature and do not finish well on grass until 3 or 4 years of age. So long as an export outlet existed, there was a good demand for them. This demand, however, no longer exists, having practically disappeared about 1912; it was revived for only a short time during the World War period.

The eastern kosher demand for heavy beef fore quarters, chucks, and plates has been the sustaining outlet for the "export" type of steers produced in southwest Virginia during the last 15 years. Aside from the kosher trade, the demand for heavy steers is from the hotel and dining-car trade which requires Good and Choice grades. The kosher trade, too, prefers these best grades. Only a very small proportion of Virginia grass cattle meet these requirements, since the bulk fall between the average and top of Medium grade.

These facts suggest that the marketing problems of Virginia cattle raisers are closely related to their production problems, and that improvement in the market situation can best be effected by improving the type and quality of the cattle raised and by supplementing pastures with grain and other concentrates. More attention should be given to the production of lighter weight cattle of good quality which yield the smaller cuts of beef that consumers now demand.

The results obtained on fed cattle in north Virginia indicate that some cattle feeding might be done in southwest Virginia, especially on farms so situated that an ample supply of feed can be produced or obtained economically. When feeding in dry lots, cattle bought during September or October could be fed during the winter months and marketed during the following spring or early summer. These should be fed out as Medium grade steers. The success of this method depends mainly on the seasonal rise in the price of this grade of steers. If steers of higher grade were fed it would be preferable to market later in the summer. In feeding cattle for the summer market it seems advisable to feed less grain during the winter and finish on grass, supplementing the grass with grain, thus improving the finish of the cattle and possibly advancing the marketing date. This would also result in more economical production.

With the type and age of cattle now generally used, the practice of maintaining steers during the winter with large quantities of concentrates does not seem the most economical, especially if the steers are carried through the full grazing season, since neither grade nor selling price of the steers followed through the market showed any significant effect of the quantity of grain fed during the previous winter. If these cattle had been "topped out" earlier in the season they possibly would have shown more effect of the grain feeding. The Bureau of Animal Industry has found in three experiments with similar steers that an advantage of 100-pound gain in weight as a result of winter feeding was reduced to only 41 pounds after 136 days on grass. In other words, if one lot of steers weighed 100 pounds per head more as the result of better winter feeding, than another lot of steers similar in all other respects, the difference in weight would be reduced to 41 pounds after 136 days on the same pasture.

Under the present system of finishing on grass alone, effort should be made to winter aged steers as economically as possible as the main object is to maintain thriftiness and body weight. Corn silage and some dry roughage appear to be the cheapest and most satisfactory ration with which to do this. When wintering young steers it is not only highly desirable to keep them thrifty but also to keep them growing, for it is essential that they continue to grow so as to attain the desired finish during the grazing season. Young steers are efficient utilizers of roughage, but for the best development they need a protein feed like clover hay or cottonseed meal.

It was found in both north and southwest Virginia that weight and age of the steers formed an important factor in determining the economy of gains. The effect of age was least noticeable with silage-fed steers. The light, nonsilage steers in southwest Virginia and the light-fed steers in north Virginia made much cheaper gains than did the heavier, and probably older animals. The margin necessary to pay all costs was much less in both cases. At times market conditions are such as to favor the production of heavy cattle in spite of their inefficiencies in the utilization of feed, but these favorable periods are infrequent and irregular, thus making it more or less of a gamble to attempt to take advantage of them. Age therefore is an important factor to be taken into consideration for the most economical utilization of the available pastures and the most satisfactory market returns.

For the slow-maturing type of cattle now commonly produced it would seem profitable to deviate from the usual custom and purchase grazing steers one year younger than those usually bought. A young steer of the slow-maturing type may tend to put most of his gain in growth rather than to develop the desired degree of finish for slaughter purpose. The total weight gain would probably be about the same, but from a market standpoint it is desirable that the steers fatten. If the grass matures properly they probably will attain the desired finish, but in most cases some grain feeding on grass is necessary to obtain the best results.

Grass-finished steers from southwest Virginia, when strictly mature, often become a liability. After reaching a maximum finish they often "go back" or the fat becomes "patchy"; either condition lowers the value of the animal. If the steers are held too long they are expensive to maintain and at this stage are uneconomical utilizers

of grass. Frequently they are held on a declining market. This was especially true in 1923, 1924, 1928, and 1929. The seasonal high prices for slaughter steers from this section are obtained usually during the spring and early summer months. Unless conditions warrant a different procedure, steers that are ready for market during the early summer should be "topped out" and sent to market. This may be advisable for several reasons even if they have not reached their maximum finish: (1) Their total value may be more at this time than if sold on a declining market later; (2) it leaves grass for the unfinished steers that can utilize it more economically; and (3) it lessens the risk of all the cattle being forced on a glutted market at any one time or at the end of the grazing season and is a means of averaging or lessening market risks. Large graziers can do this readily, but small producers may find it necessary to make cooperative shipments.

Orderly marketing should be one of the goals of the producers in the Appalachian area who finish cattle for slaughter. Approximately 72 per cent of the slaughter cattle from southwest Virginia in 1922 were marketed during August, September, October, and November; 96 per cent moved during these months in 1923, and 94 per cent in 1924. Approximately 85 per cent of these steers graded from average Medium to low Good, and were marketed at a time when Medium grade grass cattle are marketed in greatest numbers throughout the whole country. It is not surprising that at this season of the year Medium grade steers at Jersey City often sell considerably below such grades at the Chicago market.

Cattle marketed from Virginia and West Virginia are usually loaded so as to arrive at the market at least one day before they are offered for sale. The cattle followed through the Jersey City market were unloaded an average of 36 hours before being sold. The average fill taken on by these cattle during the time they were held in the yards amounted to 64 pounds per head. This is an excessive fill, probably double the average fill on the Chicago market. A heavy fill lowers the dressing percentage, therefore experienced buyers naturally make an allowance for such fills in making purchases, otherwise they could not realize costs. This accounts in part for the price differential between live cattle of the same grades at Jersey City and Chicago.

As a rule carloads of steers received at Jersey City from Virginia run fairly uniform as to weight and grade, but often there is a "light end" and occasionally a stag or a bull in the load. Shippers would profit by loading a car with cattle that are as uniform in quality as possible, for inferior animals have an adverse psychological effect on prospective buyers and afford a talking point for beating down prices.

The practice of contracting for cattle in advance of delivery as generally followed in Virginia and West Virginia is not conducive to improvement in the quality of the stock. The actual selling qualities of the stock are overlooked, weight being the only object in view when cattle are contracted at a given price margin. Contracting cattle in advance encourages bulk-weight production and tends to cause the grazier or feeder to lose sight of quality and of the fact that it is important that he keep informed in regard to market conditions and demands. He does not know the market selling price or how his cattle grade, and he is not able to compare them with the cattle with

which they compete. The unsatisfactory conditions incident to the marketing of cattle in this section may be attributed largely to the contract system and its inevitable result—bulk production without regard to quality.

It is highly desirable that the individual grazier or feeder ship his own cattle to market if possible in order that he may become familiar with the actual market conditions which his stock have to meet. In some sections cooperative shipping is advisable. The practice of paying a commission to a friend or neighbor who is better acquainted with livestock shipping does not lead to the most efficient production and marketing system. A personal study by each livestock producer of the existing marketing system, market conditions, and consumer demands would lead to more efficient production and more orderly marketing. If every producer followed the market more closely and kept informed as to the grade and market value of his product, there is reason to believe that a more united effort would result in an improvement in the entire marketing and production situation in the sections embraced in this bulletin.

SUMMARY

The production of beef cattle on pasture has long been an important industry in Virginia. The leading cattle-producing sections in the State are southwest Virginia, the Shenandoah Valley, and north Virginia. The 34 counties in these three sections had 78 per cent of all the beef cattle in the State according to the 1925 census.

In southwest Virginia steers are purchased as feeders in the fall and after grazing on pasture until early December are wintered on shock corn, hay, and silage. In late April they are turned on grass and are grazed until ready for market in the late summer or early fall.

In the Shenandoah Valley and in north Virginia the feeder steers are purchased in the fall, but the more common practice in these sections is to feed more liberally on shock corn, cottonseed meal, silage, and hay in dry lot, for 75 to 110 days and market them during the winter. Such cattle compare about equally with the "short-fed" or "warmed-up" steers of the Corn Belt. The usual practice in all three sections is to have steers ready for slaughter at 3 to 5 years of age and weighing, at markets, from 1,250 to 1,500 pounds.

From 1870 to 1912 many of these steers were exported alive to England, but after 1912 this export trade practically disappeared. The large export trade in fresh beef which the Nation enjoyed during this time also dwindled to practically nothing after 1912, although it was restored temporarily during the World War period. Virginia cattle that are not used for local consumption now find their chief outlets in the large consuming centers north of the Potomac River. The principal markets to which they are shipped are Baltimore, Lancaster, and Jersey City. A limited number are sent to Richmond. Cattle going to Lancaster are mostly purchased for further feeding in Pennsylvania and Maryland feed lots. Those going to Baltimore and Jersey City are usually bought for immediate slaughter.

Loss of the export trade in cattle and beef, and changes in cattle numbers resulting from the operation of the cattle-production and cattle-price cycles, together with changes in consumer demand and changes in cattle-production methods in other sections of the country have all resulted in creating new and difficult problems for Virginia

cattle producers. To meet these problems and place their industry on a more profitable basis, producers apparently must make some readjustments in their production methods. Improving the grade by use of better breeding stock and by feeding some grain or other concentrates during the grazing season appears to offer possible means of bettering conditions. To market steers at younger ages is desirable.

In marketing their cattle, Virginia graziers who operate on a large scale frequently consign their steers to the public markets, but the more common practice of the other graziers is to sell at home to local buyers who ship to market, or to representatives of slaughterers located in the large eastern cities. In many instances the local buyer or packer representative is also a large-scale grazier. Frequently the local buyer furnishes the feeder cattle for grazing and contracts to buy them back at the end of the grazing season. Contracting for cattle several months in advance of delivery has been a common practice for many years.

The railroad facilities available to the livestock shipper are usually the most important factor in determining his choice of a market. The railroad system that serves the stockmen in southwest Virginia provides direct transportation to Lancaster and Jersey City, hence most of the cattle shipped from that section are consigned to these two markets. On the other hand the system that serves most of the stockmen in the Shenandoah Valley and in north Virginia provides direct service to Baltimore, and this accounts for a large proportion of the shipments from this territory going to that market.

Railroad records show that for the three years, 1922–1924, cattle shipments from southwest Virginia averaged almost 2,500 cars annually. During this period about one-third of the shipments were sent to Jersey City and New York. Approximately 12 per cent were consigned to slaughterers in Philadelphia, and almost 40 per cent went to Lancaster and other points in Pennsylvania. Less than 2 per cent were shipped to Baltimore. Virginia's contributions to Lancaster's car-lot receipts of cattle have ranged from 20 to 30 per cent annually. Cattle shipments from Virginia to Jersey City for sale comprise, on the average, about 30 per cent of the total receipts at that market which are offered for sale. West Virginia furnishes about 13 per cent of the total for sale at that market.

The bulk of the cattle marketed from Virginia are shipped during a comparatively short period each year. The grain-fed cattle from north Virginia and the Shenandoah Valley are marketed from early December to the middle of March. Most of the cattle in the State, however, are fattened on grass, and these are marketed mostly from mid-August to late November. The marketing period for the grass-fed cattle may be advanced or delayed, depending upon pasture and market conditions, but the former factor is the more important. A prolonged rainy season usually prevents the cattle from acquiring the desired finish and thus delays the marketing period. On the other hand a dry summer hastens the curing of the grass, and the steers are made ready for market early. Ordinarily Virginia and West Virginia contribute about 70 per cent of the cattle on sale at Jersey City during the 12 weeks following August 15, and during this period about 80 per cent of the shipments from southwest Virginia move to market. Approximately 90 per cent of the receipts from Virginia at Lancaster arrive in the second half of the year.

Cattle fattened in the feeding district of Lancaster, Pa., are marketed from April to June, inclusive, or, when there are practically no shipments moving to market from Virginia or West Virginia.

Records obtained on the operations of a number of graziers in southwest Virginia showed that about 75 per cent of their steers were wintered on shock corn, hay, and straw. The others were wintered on silage and lesser quantities of grain and dry roughage. The quantity of corn and other feeds fed per steer on different farms varied considerably. On some farms steers received as much as 20 bushels of corn per animal; on other farms they were fed very little grain.

The quantity of corn fed per steer before going on grass in the spring averaged 6.5 bushels where silage was used, and 13.9 bushels where the roughage was mostly hay and corn stover. Steers receiving silage also received, in addition to the corn, an average of 48 pounds of other grain and concentrates, 592 pounds of hay, 1,033 pounds of corn stover, and 653 pounds of straw. The quantities of silage fed during the period averaged 3,447 pounds. Steers not receiving silage were given an average of 1,501 pounds of hay, 1,665 pounds of corn stover, 711 pounds of straw, and 93 pounds of grain and concentrates other than corn.

On the basis of values prevailing at the time the records were taken the wintering feed cost was about $4.75 per steer lower for steers that received a silage ration with a limited quantity of corn than that for steers fed larger quantities of corn, and roughages consisting mostly of hay and corn stover. There was but little variation in the other costs, and this margin in favor of steers wintered on silage was maintained throughout the wintering and grazing periods.

The average daily gain in weight per steer during the entire season was practically the same for each method of wintering, amounting to 0.8 pound. The total gain for the entire season averaged approximately 300 pounds. The cost per 100 pounds gain for steers receiving silage, however, was $2.31 lower than for steers wintered mostly on shock corn, hay, and straw.

Records obtained in north Virginia and the Shenandoah Valley were on steers fed in dry lot for a period of about 90 days. During this period these steers received about the same total quantity of hay and other roughages as was fed to steers in southwest Virginia wintered on silage. They received considerably more silage and concentrates, and their average daily gain in weight was two and one-half times as great, amounting to 2.03 pounds. The cost per 100 pounds gain in weight was slightly higher than for the grass-finished steers in southwest Virginia, but this was partly because of the higher unit cost of corn.

Although the records obtained were hardly sufficient in number to allow general conclusions to be drawn with regard to the advantages and disadvantages of using light and heavy feeder steers, there were indications that lighter steers make gains in weight at lower costs than do heavy steers. This was particularly true for the steers fed in the Shenandoah Valley and north Virginia and those in southwest Virginia that did not receive silage.

Grass-finished steers in southwest Virginia, held on the farm for an average of 341 days, made a greater daily and total gain in weight than did steers kept an average of 378 and 424 days respectively, and the cost per 100 pounds gain was less for the steers held for the shorter

periods. Likewise steers fed for an average of 60 days in dry lot in north Virginia made a greater average daily gain than did those fed approximately 100 days, and the cost of gain per 100 pounds was less.

Shipments of steers followed to market averaged about 18 to 20 animals per car. Gross shrinkage in transit averaged about 9 per cent of home loading weights. The time in transit averaged 55 hours to Lancaster and 64 hours to Jersey City. The steers had access to feed and water for an average of 40 to 50 hours after arrival at market before being offered for sale. This enabled them to regain about half of the weight lost in transit and reduced the net shrinkage to an average of 4 to 5 per cent. There were wide variations, however, in both gross and net shrinkage.

Excluding shrinkage, average total marketing costs for steers from southwest Virginia amounted to $183.64 per car, $10.12, per head, and 70 cents per 100 pounds shipping weight. Freight cost was the largest single item, averaging $128.12 per car, with the rate ranging from 53 to 55½ cents per 100 pounds arrival weight. Commission charges were $1.25 and yardage 40 cents per head. Steers shipped from north Virginia and the Shenandoah Valley to Jersey City were marketed at a cost of $160.38 per car, $8.06 per steer, or 60 cents per 100 pounds shipping weight. The lower cost as compared with that for the steers shipped from southwest Virginia was due primarily to a difference of about 10 cents in the freight rate as a result of the shorter haul.

Steers shipped from southwest Virginia to Lancaster were marketed at an average cost of $166.88 per car, $8.31 per steer, or 65 cents per 100 pounds shipping weight. Freight costs were slightly lower as were also yardage and feed costs at market. Lower feed costs were due to smaller quantities of hay fed as well as lower unit costs.

Marketing costs on cattle purchased by packers at Chicago and shipped to Jersey City or New York for slaughter approximate about 63 cents per 100 pounds. This includes only buying commission, freight charges, and cost of feed in transit. The cost on shipments from Kansas City to New York is about 90 cents per 100 pounds.

The yield of beef from steers marketed at Jersey City from southwest Virginia averaged 56.3 per cent of their sales weight; the carcasses averaging 773 pounds. The range in dressing percentage was 53.55 to 58.5 per cent, with approximately 70 per cent of all the steers ranging between 55 and 57.5 per cent. Steers from north Virginia and the Shenandoah Valley yielded a slightly smaller proportion of beef to live weight, their dressing percentage averaging about 55.2 per cent. The lighter weight of these steers and a slightly greater fill at markets account for their lower dressing percentage.

Steers from north Virginia graded slightly higher, both alive and in the carcass, than those from southwest Virginia. Approximately 85 per cent of the latter graded from average Medium to low Good; the remainder graded down to the low end of Medium with a few steers grading as low as Common. Those from north Virginia and the Shenandoah Valley graded from average Medium to average Good, a large proportion being in the upper range.

Virginia cattle marketed at Jersey City are slaughtered mostly for the kosher beef trade of New York City. The fore-quarter beef which meets the kosher requirements is consumed by the orthodox Jews and the hind quarters are sold to the non-Jewish trade. The requirements and peculiarities of the kosher trade are an important

price-determining factor for Virginia cattle, and variations in the demand of this trade resulting from the occurrence of Jewish feast and fast days need to be considered by shippers of cattle to the Jersey City and New York markets. New York City takes about 10 per cent of the total beef of the country obtained from federally inspected slaughter and almost 20 per cent of the steer beef. Ordinarily it requires the beef from approximately a million cattle, excluding calves, to feed its large population each year, but it is a very discriminating market and prices there vary widely according to quality.

Although slaughterers at New York and Jersey City buy a large proportion of their cattle at Chicago and other mid-western markets, the Chicago prices for steers of the same grade as those offered for sale at Jersey City are higher than Jersey City prices slightly more than half of the time. Ordinarily Jersey City prices are higher than Chicago prices only when heavy steers sell at a premium over lightweight steers. Excessive fills at Jersey City, as a result of the long time that cattle are held on feed and water before they are offered for sale, and frequently undesirable characteristics which make the beef from these cattle difficult to sell in a discriminating market like New York, account in large part for the fact that Jersey City cattle prices are often lower than those at Chicago.

Since most of the beef cattle produced in Virginia and West Virginia are finished on grass and are marketed in the late summer and fall, they enter into competition with the large supplies of grass cattle produced in other sections of the country which are marketed at this time of year. Furthermore they are forced to meet the increasing competition from the grain-fed cattle of the Middle West, most of which are younger in age and lighter in weight and dress out beef that is higher in quality and finish. The increasing demand on the part of urban consumers for the better grades of meat and for small cuts, which can be obtained from yearlings and lightweight steers, makes it difficult to sell beef of the grade and carcass weights obtained from the type of steers commonly marketed off grass from Virginia.

Heavy steers ordinarily sell to some advantage over lightweights in the kosher trade, however, and for this reason Virginia grass steers command a higher price than the lighter-weight western grass steers of comparable grade. New York dealers who handle beef from Virginia cattle attempt to substitute it for beef from grain-fed steers, but such attempts often bring complaints from customers because a considerable percentage of the beef from Virginia steers is darker in color than the beef from steers fattened on grain. About 25 per cent of the steers from southwest Virginia, which were followed through the slaughter plants, dressed out beef that was dark in color. Such beef usually has to be sold at a discount below that which is of a bright-red color, and this is a factor that must be taken into account by Virginia cattlemen in meeting the competition from grain-fed cattle.

The factors that account for the differences in the color of beef have not as yet been definitely determined although various opinions prevail as to the reasons for color differences. Those who have had experience in the handling of beef generally agree that it is impossible to determine before slaughter which animals will yield beef that is dark in color, and they state that, as a rule, the color can not be determined from the external appearance of the carcass. It is only

when the flesh is cut so as to expose the internal muscular tissues that the color can be determined accurately.

Possibilities of improving the grade and market value of their cattle by supplementing pasture with grain and other concentrates during the grazing season appear to offer the best way of increasing the returns to Virginia stockmen. Experiments conducted over a period of three years by the Bureau of Animal Industry and the West Virginia Experiment Station indicate that steers wintered according to the usual practices in Virginia and West Virginia, but given supplemental rations of corn and cottonseed meal while on grass during the grazing season, made an average gain in weight 37 per cent greater than did steers that were on grass alone.

The feeding of grain to steers that were on grass increased their selling price about 10 per cent over the price paid for strictly grass-fed steers, and the profits from the grazing operations were 20 per cent greater where grain was thus used. One of the significant developments of the experiment was the fact that better results were obtained with feeder steers of Medium grade than those of Good grade. The steers on grass that received grain acquired more finish and improved in quality over those fattened on grass only, consequently they commanded a higher price on the market.

Records for nine years show that in the months when Virginia grass cattle are usually marketed, Good grade steers at Chicago sell at an average of $2 per 100 pounds higher than do Medium grade steers, and that at Jersey City the differential in favor of Good grade steers is about $1.64 per 100 pounds. Improving the grade of his steers by the use of grain enables the producer to obtain this additional margin in price. Feeding of grain to cattle on grass makes it possible to have them ready for market earlier in the summer, when a higher price level is usually prevailing; thus the selling at a date near the low point of the decline, which ordinarily takes place as the season advances, is avoided.

In general the marketing problems of Virginia cattle raisers are closely related to their production problems. Improvement apparently can best be effected by improving the type and quality of their cattle by the use of better breeding stock, by giving more attention to having cattle ready for market at younger ages and lighter weights, and by improving the grade by supplementing pasture during the grazing season with grain and other concentrates.

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THE PHARMACOLOGY OF THALLIUM AND ITS USE IN RODENT CONTROL[1]

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CONTENTS

	Page
Introduction	1
Review of the literature on thallium	2
Occurrence and properties	2
Determination	3
Action of thallium on bacteria	4
Action of thallium salts on animals	4
Action of thallium salts on man	8
Medicinal uses	10
Antidotes for thallium poisoning	12
Laboratory experiments	12
Method adopted for feeding experiments	12
Laboratory experiments—Continued.	
Feeding experiments	13
Physiological action on rats	18
Toxicity of thallium to rabbits by intravenous injection	18
Summary	19
Literature	19
Laboratory experiments with rodents	20
Conclusions	20
Bibliography	21

INTRODUCTION

The use of thallium as a rodent poison apparently originated about 1920, when a company in Germany introduced a proprietary rat poison that had thallium as its toxic principle. Very few reports upon its action were found in the literature previous to July, 1924, when samples of poisoned grain and rat paste were obtained from this company for study. Preliminary examination showed that these products were toxic to wild and to white rats and led to an investigation of the minimum lethal dose of thallium salts when fed to white rats and when intravenously injected into rabbits.

In August, 1925, the authors conferred with a representative of this company regarding the nature, mode of action, and use of its product in Germany and concerning plans for introducing it into the United States. The product was thoroughly discussed, and certain mimeographed circulars and information, as well as the company's method of chemical analysis, were submitted by the representative.

Thallium compounds were introduced into use for the control of rodents, particularly certain species of prairie dogs and ground squirrels that had refused to take strychnine baits. Arrangements

[1] The experiments here reported upon were instituted as a cooperative project between the then Bureau of Chemistry and the Bureau of Biological Survey prior to the appointment of the senior author as consulting pharmacologist with the Biological Survey, following his service in the pharmacology laboratory of the Bureau of Chemistry, now part of the Food and Drug Administration.

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were made with two American companies to supply the poison in commercial quantities. A number of reports by field agents of the Bureau of Biological Survey have already indicated the value and use of thallium products in field practice. The difficulties encountered by E. E. Horn, district investigator in the control-methods research project of the bureau, in obtaining acceptance by rodents of certain thallium baits led to the study of six commercial thallium products.

The methods employed in the feeding tests are essentially the same as those used in the previous pharmacological and toxicological studies of other rat poisons (arsenic, strychnine, barium carbonate, and squill) undertaken cooperatively by the Bureau of Biological Survey and the pharmacology laboratory of the Bureau of Chemistry (now the pharmacology unit of the Food and Drug Administration). The literature on thallium through 1896 was listed by Doan (*63*).[2] In the present bulletin, all available information in the literature has been consolidated, as well as the results of the feeding experiments with thallium compounds conducted by authors. So far as possible the original articles have been consulted.

REVIEW OF THE LITERATURE ON THALLIUM

OCCURRENCE AND PROPERTIES

Crookes (*53*) extracted thallium with selenium from the deposit of a sulphuric-acid factory at Tilkerode, in the Harz Mountains, Germany. When examined spectroscopically, a new spectrum was obtained in which a green line at 1442.6 on the Kirchhoff scale, corresponding to $\lambda=5{,}350.7$ Å, was the outstanding characteristic. Since the green line recalled the fresh color of vegetation in spring, Crookes named the new element "thallium" from the Greek θαλλός (a young shoot). This discovery was announced in 1861. Lamy, two years later (*94*), observed the green spectral line from the sulphuric-acid deposit at Loos, France, where Belgian pyrites were roasted. He claimed that 0.000,002 milligram of thallium could be detected by its flame spectrum (*107*).

Uncombined thallium has not been found. It has been estimated that the hydrosphere and lithosphere of the earth contain less than one part of thallium per billion, and it is not shown in the solar spectrum (*107*). Lorandite ($TlAsS_2$), from Macedonia, contains 59.5 per cent of thallium associated with realgar. Urbanite, from Macedonia, contains 30 per cent of thallium. Hutchinsonite, a sulpharsenide of thallium, lead, silver, and copper, contains an appreciable quantity of thallium. The Swedish mineral crookesite, with a composition agreeing with $(Cu, Tl, Ag)_2Se$, contains 16 to 18.5 per cent of thallium. Fractions of 1 per cent have been reported in cupriferous pyrites from various sections of the world; and also in lepidolite, zinc blende, pitchblende, pyrolusite, manganite, carnallite, certain mineral waters, natural sulphur, and many minerals. It has been obtained from lead-chamber deposits in the manufacture of sulphuric acid by the roasting of pyrites or raw sulphur (*88*, *108*).

[2] Italic numbers in parentheses refer to Bibliography, p. 21.

Lamy obtained thallium by neutralizing the slime in the lead chamber of a sulphuric-acid plant with lead oxide or calcium oxide and extracting with hot water. The solution was concentrated, and thallous chloride was precipitated by the addition of hydrochloric acid. After washing with dilute hydrochloric acid, the product was decomposed with sulphuric acid, and impurities were removed by hydrogen sulphide. The filtrate was concentrated and metallic thallium precipitated by zinc or by electrolysis. Thallium has also been obtained by extraction by sodium carbonate, precipitation of thallous sulphide in the presence of potassium cyanide, oxidation to sulphate, and precipitation with zinc. The precipitated metal is fused in a stream of hydrogen or in the presence of oxalic acid to prevent oxidation. A number of various modifications of these methods have been suggested (*66*, *84*, *87*, *107*).

Thallium is a soft, white metal with a grayish tinge, resembling tin in appearance. When exposed to the air, a dark-gray film of oxide rapidly forms, which is soluble in water. On paper the metal makes a mark resembling that produced by metallic lead. It has a specific gravity of 11.8, is somewhat softer than metallic lead, and is very malleable. Its chemical symbol is Tl, and its atomic weight 204. Thallium forms two series of salts—thallous compounds, in which the metal is monovalent, and thallic compounds, in which it is trivalent. By treating the metal, the oxide, or the hydroxide with the proper acid, a series of salts is obtained. These are usually white crystalline products, soluble in water.

Thallic salts are reduced to thallous salts on boiling, which process precipitates insoluble thallic hydroxide. Microscopically, 0.0016 milligram of thallium has been detected by precipitation of thallous chloride and 0.003 milligram by precipitation by yellow thallous iodide. Thallous sulphide (Tl_2S) is incompletely precipitated by hydrogen sulphide in the presence of mineral acids and completely precipitated in the presence of acetic acid. The sulphide is not soluble in ammonium sulphide (*107*, *108*, *122*). The existence of a number of sulphates has been claimed (*107*, *108*). Pale-yellow thallous chloroplatinate is precipitated on the addition of hydrochloroplatinic acid, and it is claimed that this reaction will detect 0.000,008 milligram of thallium.

Thallium has been employed in the manufacture of optical glass and in the electric-lamp industry. The acetate, the sulphate, and the nitrate have been used in medicine.

DETERMINATION

Thallium may be qualitatively determined by the characteristic green line in the spectrum (*53*, *100*, *107*), as well as by chemical methods (*133*). The detection of 0.000,008 milligram of thallium by precipitation with chloroplatinic acid has been reported. Olmer and Tian (*114*) claim that the limit of detection with a spectroscope is 1: 500,000,000 (0.002 milligram per liter, or 2 parts per billion). In a Marsh apparatus, a stain is produced somewhat similar to an arsenic stain; however, the thallium stain produces a yellow color with iodine and is insoluble in ammonium sulphide.

The quantitative method of determination as furnished by the German company is as follows:

About 1 gram of paste or 2 grams of grain is weighed and intimately mixed with 15 to 20 grams of sodium carbonate (anhydrous) in a 70 c. c. porcelain crucible.

Heat for 1½ hours just under fusion temperature. Cool and transfer contents of crucible to a beaker or Erlemeyer flask containing 50 c. c. of water. Wash the crucible thoroughly with dilute hydrochloric acid and add the washings to the flask. When all the sodium carbonate has been decomposed with hydrochloric acid, a large excess is added (about 20 to 25 c. c.) and the liquid heated to boiling. Potassium chlorate is added slowly until probably 2 grams has been added and the liquid smells strongly of chlorine.

Evaporate till salt separates, add more water (150 c. c.), and evaporate again. Be sure that no free chlorine is in the liquid. Cool and add 10 to 15 c. c. of N/10 sodium thiosulphate and 1 gram of potassium iodide. Let stand 5 minutes and titrate the thiosulphate with N/10 iodine solution.

Calculation:

$$\frac{40{,}000:508=\text{No. c.c. } Na_2S_2O_3.5\,H_2O:x}{\text{Weight of sample in grams}}\times 100=\text{per cent } Tl_2SO_4$$

This method gives good results and requires no particular skill to operate.

ACTION OF THALLIUM ON BACTERIA

Buschke and Jacobson (*23*) reported in 1922 that thallium has a strong oligodynamic action on *Bacillus coli*, typhoid and dysentery bacteria, streptococci, and staphylococci, but not on molds. When a piece of metallic thallium is placed in the center of an agar plate containing viable organisms, a clear zone of dead bacteria is produced over an area 7 to 14 millimeters in diameter. This action disappears when air is removed, but returns upon reexposure, a result suggesting that air oxidizes Tl to Tl_2O, which dissolves to form TlOH (*21*). Concentrations of thallium acetate or carbonate as strong as 1:1,000 (1,000 milligrams per liter) are required to inhibit the growth of *Bacillus coli*.

The cost and the scarcity of metallic thallium prevent commercial application of this property.

ACTION OF THALLIUM SALTS ON ANIMALS

GENERAL ACTION

Lamy (*94*), who was working upon thallium in France at the time Crookes discovered it in England, offered milk containing 5 grams of thallium sulphate to two young puppies; they drank only a small quantity, then refused to drink the remainder. In spite of every effort to save them, both died in four days. Six ducks, two hens, and a dog consumed a portion of the milk solution. During the day the dog became restless, salivated, and refused food; during the night, constipation and respiratory distress developed. The hind limbs of the dog and the legs of the ducks and hens became paralyzed. All animals died or were moribund 64 hours after taking the milk thus treated. Ten milligrams of thallium sulphate killed another dog in 40 hours, with manifestation of the same symptoms.

Grandeau (*80*) found in 1863 that 1 gram of thallium sulphate killed a dog in five days with all the symptoms of lead poisoning, whereas in another dog 1.5 grams of lead acetate caused emesis, but

with eventual recovery. This led Paulet (*117*) to the conclusion that thallium was more toxic than lead.

In Blake's (*9*) experiments in 1890, 90 milligrams of thallium sulphate, intravenously injected into the jugular vein of a rabbit, stopped the pulmonary circulation for a few seconds, and a second dose killed; injected into the carotid artery, doses up to 350 milligrams were apparently inactive, but 750 milligrams killed by stoppage of pulmonary circulation. Small doses of thallium salts were tolerated for some time, but the effects were cumulative. Impairment of appetite, emesis, and diarrhea, followed by obstinate constipation, hemorrhages, tremors, lack of muscular coordination, conjunctivitis, general debility, and depression of respiration and circulation, were produced in animals. Post-mortem examination showed effusions of blood into the lungs, congestion of the gastro-intestinal tract, pericardial effusions and ecchymoses of the surface of the heart. Thallium was eliminated in all secretions.

Jones (*89*) demonstrated the presence of thallium in the urine of rabbits two hours after oral administration. There is no known antidote, according to Marme (*105*). Rabuteau (*124*) showed in 1874 that the muscles would not respond to stimuli after death from thallium. Curci's (*55*) experiments revealed that circulation and respiration were both depressed in frogs; in warm-blooded animals, weakness and collapse were produced, the pulse was slowed, and the blood pressure increased.

Kobert (*93*) reports Luck's experiments (*100*) in which the flesh of a hen poisoned by thallium was fed to 11 rats, all of which died. Cats fed the same vomited, but survived. Spitzer (*139*) killed rats in four days by the application of a paste containing 5 per cent of thallium; a 20 per cent salve killed in two days. Local applications did not cause loss of hair. Cataracts were produced in these animals.

An intensive study of the action of thallous acetate, nitrate, and sulphate was reported by Swain and Bateman (*141*) in 1909. The thallous salts were prepared directly from metallic thallium, and all thallic compounds removed. All results are reported in terms of the metal thallium, regardless of the salt actually injected. The lethal dose of thallium as the acetate injected directly into the lymph sac of the back of 300-gram toads was approximately 16.7 milligrams per kilogram of body weight. Death from respiratory failure followed loss of control of the hind legs.

A toadfish (Porichthys) weighing between 30 and 50 grams died within 50 hours in a 1:2,500 solution of thallium as the chloride (400 milligrams per liter) after exhibiting signs of respiratory distress. Another toadfish died in 53 hours, after two days' contact with the same solution. A concentration of 800 milligrams per liter caused death in 20 hours. A rock cod (Cottidae) died from respiratory distress in a few hours in a solution containing 400 milligrams of thallium per liter. Injection of a solution into the lymphatic trunk just behind the lateral fin was then attempted. A "blue cod" (*Ophiodon elongatus*) died the next day after 20 milligrams per kilogram; a bluefish (Sebastodes) died in four days after 10 milligrams per kilogram, and another in three days after 16 milligrams per kilogram.

Subcutaneous injections of 20 and of 45 milligrams of thallium as the nitrate killed rats in 2 days; 15 milligrams killed two guinea

pigs in 5 days; 20 milligrams killed a rabbit in 4 days and another in 6 days, and 40 milligrams in 4 days. Unfortunately, however, the body weights of the animals are not reported, so that calculations of results in the customary terms of milligrams per kilogram can not be made. A dog received 100 milligrams subcutaneously (11 milligrams per kilogram), which caused posterior paralysis and loss of appetite for 10 days, although the animal survived.

TABLE 1.—*Toxicity of thallous salts administered orally to dogs, as determined by Swain and Bateman (141)*

Salt used	Days until death, after doses (in milligrams per kilo of body weight) were given of—					
	13	17	19	20	26	45
Thallous acetate ($TlC_2H_3O_2$)	8		9, 15			
Thallous nitrate ($TlNO_3$)		15		7		4
Thallous sulphate (Tl_2SO_4)					12	

Oral administration to dogs gave the results listed in Table 1. The minimum lethal dose can not be determined from these data, since all test animals died, but it appears to be less than 13 milligrams per kilo.

The authors conclude that thallium is more toxic than lead, being about as potent as arsenic. The administration of 200 milligrams to a dog over a period of 13 days produced the same effect as when administered in 4 days, from which the authors conclude that there is no tolerance for thallium, but a cumulation of action.

The first symptom noted by Swain and Bateman after administration of thallium was lack of coordination in locomotion, localized in the hind legs of the quadrupeds. Trembling, great dilatation of the pupils, emesis, congestion of the gastrointestinal tract, increasing albuminuria, increased urinary volume, and alopecia were noted in most animals; dogs also showed a marked increase in the flow of tears and of bile. A blue line appeared upon the gum margins. Finally respiratory distress developed to cause death by asphyxia. There was no indication of heart failure, toads' hearts continuing to beat for some time after the respiration ceased. Some lesions of the kidneys were noted after 200 milligrams (17 milligrams per kilo) were given, but they were not considered sufficiently severe to cause death, and the suggestion is offered that thallium may favor the production of uremic poisoning. Nephritis was established.

Herfs (*5*, *86*) in 1924 lauded thallium highly; he claimed that 70 milligrams of thallium per kilo killed rats in 2 days and that smaller doses killed in 8 to 14 days, by action upon the central nervous system. House mice were killed by 2 or 3 grains of thallium-treated wheat; 10 mice consumed 262 of 400 kernels of normal wheat and 304 of 400 treated kernels. Cataract was not observed.

In perfusing isolated frog hearts by the Straub method, 0.03 to 0.05 milligram of thallium sulphate caused stoppage of the heart in diastole in 10 to 15 minutes (*23*). The action was antagonized by the addition of calcium to the perfusion solution. Retardation of growth of rats and other warm-blooded animals by thallium is due

to disturbances of the calcium metabolism (*21*, *33*, *35*, *37*). Because of these disturbances, conditions resembling rickets are produced, with a progressive failure of the body tissues to store calcium. Histological examinations of the skeletal bones showed definite evidence of rickets (*35*, *37*).

In a further series of papers (*13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*, *22*, *25*, *26*, *27*, *28*, *29*, *31*, *32*, *34*, *38*, *39*, *40*, *41*, *43*, *45*, *78*), Buschke and coworkers showed that thallium poisoning was developed through its actions upon various endocrine glands. This accounts for the failure of tadpoles to grow in very dilute solutions of thallium salts. The action is specifically exerted upon the ovaries or testicles, which may completely atrophy; in a number of rats, complete loss of the testicles was produced; in others no spermatozoa could be found. The epinephrine content of the suprarenal glands was greatly decreased. Involvements of the thyroid gland were also found. Evidence regarding the effect upon the pituitary gland was not so definite, although some involvement seemed demonstrable. Cataracts were produced in rats (*78*) and also proliferation of the mucosa of the cardiac end of the stomach.

Dal Collo (*48*, *49*) confirmed the endocrine action of thallium upon rabbits. Six rabbits weighing 2,500 to 2,800 grams were given 10 milligrams of thallium acetate intravenously the first day, and the daily dose increased 10 milligrams until death supervened on the fifth or sixth day. Guinea pigs were given 1 milligram subcutaneously the first day, and the dose increased by 0.5 milligram a day until death, on the thirteenth to sixteenth day. Rats were fed 1 milligram daily in their food. All animals showed parenchymatous and vascular nephritis, with characteristic epithelial lesions, and diffuse changes in the convoluted tubules.

Transitory hyperglycemia, followed by constant hypoglycemia; sexual changes, but no congenital eye lesions or lesions of the bones or parathyroid gland; leucocytosis; and erythropenia were observed in rats following the administration of thallium salts. No relation or interdependence could be established between alopecia, hypertrophic processes, bone lesions, and the appearence of cataracts by Mamoli (*103*, *104*) in 1926.

Olivier (*113*) observed that long feeding of small doses of thallium to rats caused inflammatory proliferations of the mucosa of the esophagus and cardiac end of the stomach. Ehrhardt (*69*) went a step further in the study of the action of thallium upon the newborn; a female rat was fed large doses of thallium for four days, after which she died. The nursing young were at once transferred to a normal lactating rat and fed her milk, but all showed the typical effects of thallium poisoning. This clearly demonstrates the harmful action of thallium upon the young, whether the transference occurs in utero or in the milk.

Buschke and Peiser (*38*) experimented with an organic thallium compound, thallium dimethyl bromide. The lethal dose to mice was found to be 5 to 6 milligrams per mouse, or 10 times the lethal dose of thallium acetate. Similar symptoms were produced. The hydrogen-ion concentration of thallium solution influenced the rate of amphibian metamorphosis (*7*). The pathological changes produced in various animals by thallium have been investigated by

various workers (*51*, *85*, *95*, *102*, *110*, *134*). Popenoe (*121*) suggested the use of thallium as an ant poison.

PRODUCTION OF ALOPECIA (LOSS OF HAIR)

Several investigations have been made to determine the nature of thallium action in the production of alopecia (*8*, *61*, *70*, *71*, *145*, *148*). In 1898, Hallopeau (*83*) rubbed a salve containing thallium acetate upon the back of a guinea pig; the pig died but the hair was unaffected. In 1900, Buschke (*13*) observed that the feeding of very small quantities of thallium to rats produced alopecia, and had a cumulative action. In a subsequent report (*14*), he noted that thallium acetate or carbonate produced alopecia in mice, rats, and monkeys; in rats it had a central action, since the diaphoretic action of pilocarpine was not altered. The series of papers by Buschke and coworkers clearly demonstrated that thallium action was exerted upon the sympathetic nervous system. The hairs of the scalp and chest, under the control of the autonomic nervous system, were loosened readily by thallium; the hairs of the eyebrows and lashes, and those upon the abdomen not under the control of the autonomic system were unaffected. One-tenth of a milligram of thallium acetate fed rats daily produced alopecia (*39*). Other workers also showed that the hairs upon the scalp and abdomen were most readily removed; lanugo and abdominal hairs with more difficulty; hairs at the nose and snout not affected. The local application of thallium did not cause loss of hair. A 5 per cent thallium acetate salve killed rats in four days; 20 per cent in two days; more rapid deaths were not produced (*113*, *139*).

Dixon (*62*) reported a very thorough study of the mechanism of depilation by thallium. He found that no other substance has a similar action in producing alopecia; that thallium has this action upon all animals with the possible exception of the guinea pig. The hair at first becomes less glossy, then is easily rubbed off after about seven days. After 14 days it is easily shed, practically all hair being out by the nineteenth day. Alopecia begins at the nape of the neck and around the ears; hairs from the chin and the nose are the last to be lost. The new growth of hair starts in about the fourth week, and is completed by the end of the second month. Local applications of thallium did not cause depilation or affect the blood vessels. Interruption of growth of the hair was due to failure of transition of the large polygonal cells to stratified cells of the hair. Very large doses caused degeneration of the hair follicles. Thallium was found to increase selectively the reactivity of the entire autonomic nervous system, just as strychnine increased the activity of the spinal cord. Thallium was excreted in the urine, but did not appear to injure the kidneys or to cause albuminuria. Spectroscopically it was found in practically every tissue of the body.

Truffi (*143*) found that rats were more sensitive than guinea pigs, cats, or rabbits. Inunction gave circumscribed depilation, because of action on the hair follicles.

ACTION OF THALLIUM SALTS ON MAN

During his original work in 1863, Lamy (*94*) developed general lassitude and pains of the lower limbs, which he attributed to the

vapors of thallium. Crookes (*54*), however, stated that he had not been affected by thallium fumes, or by the ingestion of 65 to 130 milligrams of thallium salts. According to Bullard's report (*12*), the ingestion of between 130 and 250 grains (of thallium acetate?) during a week produced diarrhea, muscular weakness, and tenderness over the nerve trunks. Since, however, both lead and arsenic were found in the urine in this case, this result should not be ascribed to thallium alone.

Olmer and Tian report a case in 1908 (*114*) in which the application of a thallium-acetate salve to the chest and thorax of a 27-year-old man produced violent pains, especially in the extremities, which were increased by pressure on the peripheral nerves; diffuse alopecia; persistent albuminuria; stomatitis; and general depression. These symptoms continued for about a month before remission. The cerebrospinal fluid collected 25 days after application of the paste showed upon spectroscopic examination the presence of 0.02 milligram of thallium per liter.

Buschke, Peiser, and Klopstock (*42*) relate that a 34-year-old printer attempted suicide by taking 750 milligrams of thallium nitrate (10 milligrams per kilo) by mouth. Marked pains in the feet and limbs, emesis, and achlorhydria were followed by alopecia in 3 weeks. New hair returned in 8 weeks, but 11 weeks were required for the return of normal gastric acidity. Slow elimination of thallium was also noted in two children.

Lührig (*101*) gives an account of a 2-year-old child who ate an undetermined quantity of a thallium paste smeared upon bread and exposed as a rat poison. Rapid collapse and vomiting were checked temporarily by injections of glucose, but a relapse followed, and the child died in 29 hours. Post-mortem examination showed nothing abnormal except marked irritation of the stomach and small intestines. Spectroscopic examination revealed the presence of thallium in various tissues. A 4-year-old child ate some of the same poisoned bait, but apparently in smaller quantities, as he survived.

Brieger (*11*) reports the death of a child in 1927 following the consumption of an undetermined quantity of thallium-coated grain, which had been mixed with grain treated with strychnine. Strychnine-poisoning symptoms were produced. After death the presence of both thallium and strychnine was demonstrated in the viscera. The death of children or of adults following the consumption of thallium-treated grain or thallium paste exposed as a rat poison has been reported only too frequently (*4*, *42*, *76*, *82*, *99*, *126*). Althoff (*4*) reported seven cases of poisoning in one family. Fridli (*76*) determined thallium by titration with potassium iodide. In a case in which 2.5 grams of thallium acetate had been taken by mouth, 5 milligrams of thallium were found in 100 grams of urine; 1.6 milligrams in 100 grams of kidney; and 3.3 milligrams in 100 grams of liver. The greater part had already been eliminated in the urine.

A recent case of poisoning by the administration of thallium acetate has attracted much comment (*3*, *91*, *135*). Through a mistake in conversion from the metric to the apothecaries' system, 85 milligrams of thallium acetate per kilo were administered instead of 8.5

milligrams per kilo. Three boys receiving this dose died after several days.

Pharmacological and toxicological studies of thallium (*77*, *81*, *115*, *128*, *129*) have been made during the past few years.

Swelling of the gums, the development of a blue line at the junction with the teeth (*122*); general muscular atrophy, especially of the jaw and spine; cardiac depression (*127*); and cardiac lesions (*106*); hypochlorhydria or achlorhydria (*64*, *75*); disturbances in calcium metabolism (*44*); severe injury to the thyroid gland (*56*, *64*); pains in the legs and sciatic nerves after 300 to 500 milligrams of thallium acetate to adults (*79*) or children (*118*); and eosinophilia and leucocytosis (*75*) have been recorded following the ingestion of thallium medicinally. Blyth (*10*) recorded the elimination of thallium in the tears, milk, and urine; he, as well as Fasani (*71*), stated that the same symptoms are produced in man as in animals, and that poisoning occurs through action on the nervous system.

Kaps (*90*) gives a good summary of the symptoms produced in criminal (fatal) subacute thallium poisoning: (1) A short period of excessive gastrointestinal pain, emesis, nausea, colic, and diarrhea, which soon changes to obstinate constipation; (2) disorders of the central and vegetative nervous system—conjunctivitis, blepharitis, alopecia totalis, acute suppurative dermatitis of the face, acroparesthesias, sensitiveness of the muscles and joints, which increases upon pressure, retrobulbar neuritis, amaurosis, and a decline of the psychic functions to complete dementia; and (3) degeneration of the heart, liver, and kidneys. The mechanism of thallium poisoning following subcutaneous injection must be sought in the action upon the central and vegetative nervous systems, with secondary disturbances of the nervous regulation of the endocrine glands. In a survey of industrial poisonings among thallium workers, Meyer (*109*) and Teleky (*142*) report reduction of vision, cataract, and nephritis. Among the principal symptoms noted were pains in the legs, loss of hair, disturbances of sensation and the sympathetic nervous system; endocrine involvements of various sorts; and lymphocytosis, which increased after work was stopped.

MEDICINAL USES

FOR COLLIQUATIVE SWEATS OF PHTHISIS

To check the night sweats of phthisis, Combemale (*50*) in 1898 recommended a dose of 100 milligrams of thallium acetate at bedtime for not to exceed four successive nights. Its value was reaffirmed by Huchard (*86*) and by Buschke (*15*). Three subsequent papers, however, were published in 1898 stressing the danger of such medication. Vassaux (*144*) recorded marked pain in the calves of the legs and in the peripheral nerves after doses of 100 and 200 milligrams of thallium acetate. Dubreilh (*68*) obtained alopecia. Jeanselme (*88*) administered 30 milligrams of thallium acetate three times a day for three days (a total of 270 milligrams), which decreased the sweating but produced pains in the abdomen and legs; after two weeks, profuse alopecia with permanent injury to some of the hair follicles resulted. Chemical analysis of the hair failed to show the presence of thallium. Because of its toxicity thallium is not used for this purpose in present-day medical practice.

AS A DEPILATORY

Thallium preparations have been used more or less empirically to remove hair in the treatment of alopecia areata and of ringworm. It is not certain who introduced this method of treatment. Olmer and Tian's (*114*) patient developed profuse diffuse alopecia after the application of a thallium paste to the chest. Sabouraud (*130*) recommended an ointment containing 1 per cent of thallium acetate as a depilatory, but stated that quantities in excess of 300 milligrams of the salt produced toxic effects. Pöhlmann (*120*) confirmed the central action of thallium in producing alopecia, and showed spectroscopically that it was eliminated by the kidneys. A symposium of the toxic effects of thallium was reported in Spain with the conclusion that the acetate was more potent than the sulphate (*132*). Buschke and Peiser (*31*) and Sabouraud (*130*) recommended the use of 3 grams of a 1 per cent salve of thallium salt as a depilatory.

Clinical reports of the use of thallium salts, more especially as depilatories, have been given in the literature of many countries (*1*, *2*, *6*, *47*, *56*, *59*, *65*, *74*, *96*, *97*, *98*, *112*, *116*, *118*, *119*, *127*, *143*, *148*). The present status of thallium therapy is well summarized in a "Miscellany" report in the Journal of the American Medical Association (*1*) and in a subsequent editorial in the British Medical Journal in 1929 (*2*). Apparently thallium was used systematically in Mexico in 1918 on account of the shortage in X-ray tubes (*2*). Cicero (*47*) found that 5 milligrams per kilo was too small a dose for satisfactory results and used 8 milligrams per kilo without serious complications.

Thallium was not so favorably received in England, perhaps on account of the lack of success in the treatment of the particular ringworm that occurred there. The doses, reactions, and cures in this series of clinical reports are given in Table 2. Thallium acetate was used in each instance.

Careful attention must be given to body weight and doses: Eight milligrams per kilo are necessary for successful depilation, smaller doses being only partially effective. Serious reactions have followed doses as small as 4 milligrams per kilo; adults are much more susceptible than children, as 8 milligrams per kilo have been toxic. The maximal dose for any patient should not exceed 300 milligrams, irrespective of the body weight. Special attention is called to the contra-indication of thallium in any cases of albuminuria or kidney involvement. Treatment should not be repeated until all the thallium from the preceding course of medication has been eliminated (two to three months). It is also emphasized that these treatments should be under the care and observation of a physician.

TABLE 2.—*Clinical response to thallium in treatment of ringworm*

Reference	Dose per kilogram of body weight	Patients' ages	Patients			Remarks
			Treated	Poisoned	Ringworm cured	
	Milligram	*Years*	*Number*	*Number*	*Number*	
Davies (*57*)	4, 5, 6	12, 14, 35	3	3		
Drummond (*67*)	5		4		4	
Peters (*118*)	5		500			Mexican schools.
Davies and Andrews (*58*)	7.5	8	1	1		
	8.5	11	1	1		
Devane (*60*)	8		45			
Seaston and Wilson (*136*)	8		30			Old solution.
	8		50	5	47	Fresh solution.
Buschke and Langer (*27*)	8		100			Berlin hospital.
Felden (?!)	8		47		36	
Peyri (*118*)	8–9		74	19	52	
Dowling and Kelman (*64, 65*)	8.5–9		90	78		
	8.5–9	Less than 3	16		16	
	8.5–9	More than 3	46		35	

Sollmann (*138*) concludes: "The therapeutic use (of thallium) has repeatedly caused severe poisoning and is scarcely justified."

ANTIDOTES FOR THALLIUM POISONING

No general antidote is known for thallium poisoning. Prompt use of the stomach tube and the induction of vomiting to remove any unabsorbed material in the stomach are indicated. As the iodide and chloride are less soluble than other thallium salts, potassium iodide or sodium chloride may be given, followed by gastric lavage or vomiting. The intravenous injection of sodium thiosulphate (*38*) gave indifferent results. Removal from exposure for several months should be adequate in cases of chronic poisoning.

LABORATORY EXPERIMENTS

METHOD ADOPTED FOR FEEDING EXPERIMENTS

It was found that thallium salts fed in ordinary food were very toxic to rats (*111*). In order to compare the toxicity with that of other rat poisons, a similar method of feeding became necessary. Some investigators dissolved the test substance in the animals' drinking water, but this method appeared too inaccurate for use in the work here reported upon. Other investigators have dissolved weighed quantities of a test substance in a known volume of water or other solvents and mixed the solution with weighed bulks of food, or administered the solution by pipette directly into the mouths of test animals. These methods appeared very cumbersome, even though somewhat more accurate in dosage.

Experience in the feeding of other poisons to rats led to the adoption of the following method of preparation of the poisoned bait: The ordinary laboratory rat food was screened, and that portion passing through a 20-mesh sieve (a sieve with 20 meshes to the linear inch, or 400 apertures to the square inch) used as a vehicle. Success in the use of this method is dependent upon the care used in finely pulverizing the poison and thoroughly mixing with a finely screened

bait. The sample of thallium compound to be tested was powdered, accurately weighed, thoroughly mixed with a weighed quantity of the sieved rat food by a spatula, and finally passed through a 20-mesh sieve several times to insure thorough mixing. Concentrations were prepared upon the basis of the actual thallium content, regardless of the salt fed. The thallium concentration in the finished baits ranged from 0.25 to 10 per cent, although 0.5 per cent was commonly used.

In an effort to standardize the condition of the rats used in these tests, all animals (wild or white) were kept under laboratory conditions for several days to a month, and fed ordinary laboratory rat food. They were then placed in individual cages and deprived of food for 12 to 24 hours to insure uniformly empty stomachs and good appetites. Water was offered at all times. The rats were carefully weighed at the end of the deprivation period, and doses of thallium were calculated in terms of milligrams of thallium per kilogram of body weight of animals. The determined quantities of bait were accurately weighed and placed in large glass sponge cups, which were introduced into the cages at a stated time. Frequent inspections were made, and the rapidity with which the different baits were attacked and consumed was noted. The sponge cup, containing any uneaten food, was removed after several hours, and the remaining quantity weighed, to determine the quantity of thallium consumed. On the next day, all animals were returned to the regular rat diet, with plenty of water. In general, the animals were kept in individual cages for a period of five days. All animals dying within five days (occasionally it took a longer time) that showed symptoms of thallium poisoning were recorded as dying from the dose consumed. The development of toxic symptoms or death was watched; in some instances post-mortem examinations were made to determine the gross changes produced by the poison.

The minimum lethal dose was taken as the quantity of thallium that caused the death of all test animals, or practically all, within the period of five days. Doses somewhat larger than the accepted minimum lethal dose must kill all test animals; doses somewhat smaller (20 to 25 per cent) killed less than half of the test animals. The minimum lethal dose is considered to be accurate within 10 to 20 per cent, which is the usual range of reaction of test animals.

FEEDING EXPERIMENTS

SERIES 1: COMMERCIAL THALLIUM-TREATED GRAIN

A sample of grain and one of a paste containing thallium as the toxic ingredient were tested in July, 1924. The grain appeared to be medium-sized kernels of wheat coated with a reddish scum. The paste was of a greenish hue and had the consistency of lard. Chemical analyses of these products were not undertaken, as analytical methods were not readily available. Count of the grain showed that 440 kernels weighed 17.5 grams and that 680 kernels weighed 27.0 grams, or an average of 25 kernels to the gram.

Seven wild rats, weighing 78 to 335 grams, were offered weighed and counted quantities of the grain at 3.30 p. m., July 25, 1924. The uneaten food was removed at 9 a. m. the next morning. All animals were alive on the second day; on the third day after feeding,

all but one died, and the survivor died during the night. Body weights and other pertinent data are tabulated for convenient reference in Table 3. The quantity of food eaten varied from 0.35 to

TABLE 3.—*Toxicity of commercial thallium-treated grain to rats*

Body weight of rats (grams)	Grain offered		Grain eaten			Days until death
	Kernels	Weight	Weight	Per cent	Grams per kilo of body weight	
	Number	*Grams*	*Grams*			
WILD RATS						
78	16	0.5	0.35	70	4.50	3
335	27	1.0	1.0	100	3.00	3
230	24	1.0	1.0	100	4.35	4
200	66	2.5	0.75	30	3.75	3
325	63	2.5	2.5	100	7.70	3
80	116	5.0	0.6	12	7.50	3
80	128	5.0	0.6	12	7.50	3
WHITE RATS						
195	12	0.5	0.5	100	2.55	4
175	12	0.5	0.5	100	2.85	4
157	13	0.5	0.5	100	3.20	2
210	26	1.0	1.0	100	4.75	3
182	25	1.0	1.0	100	5.50	3
175	26	1.0	1.0	100	5.70	3
210	62	2.5	2.5	100	11.90	3
175	64	2.5	2.5	100	14.30	3
160	58	2.5	2.5	100	15.65	3
210	125	5.0	4.0	80	19.05	3
175	127	5.0	4.15	83	23.70	3
175	130	5.0	4.75	95	27.15	3

2.5 grams, larger rats consuming the larger quantities. One gram of poisoned grain per rat killed two large rats. The minimum lethal dose was not determined, since all the test animals died, but evidently it is less than 3 grams of treated grain per kilogram of body weight (roughly equivalent to 30 treated kernels per pound of rat). Deaths occurred on the third and fourth days, even with very large doses of bait, which shows that thallium is a slowly acting poison to rats.

Twelve white rats, weighing between 157 and 210 grams, were offered weighed and counted quantities of the grain at 12.15 p. m. on August 9, 1924. All uneaten food was removed at 9 a. m. on August 11, when all rats were found to be alive and in good condition. One rat died the second day, the remainder on the third or fourth day, as shown in Table 3. A larger quantity of food was consumed by the white rats than by the wild rats, but over a longer period of time. During the same time interval, food consumption appeared to be about the same by the two varieties. No relationship was found between the quantity of poisoned grain eaten and the time until death; the earliest death occurred in a rat that had eaten 3.2 grams of grain per kilo, while others that had eaten five to eight times as much died a short time later. Thallium does not appear to kill rats rapidly, regardless of the doses consumed. Since

all animals died, it is not possible to determine the minimum lethal dose from these data, except that it appeared to be less than 2.5 grams of grain per kilo of body weight. No significance should be attached to the fact that white rats died from somewhat less than the smallest dose killing wild rats, as an insufficient number of animals were used to confirm this difference.

Three white rats, weighing 190, 205, and 212 grams, respectively, were fed a mixture of 7.5 grams of paste and 7.5 grams of rat biscuit on July 25, 1924. All animals were in the same cage. Some of the paste was uneaten after 12 hours. The heaviest rat died on the third day; the other two showed extensive diarrhea and died during the night.

On August 9, 1924, approximately 1 gram of paste was smeared on the back, between the shoulders, of each of six white rats. The rats were then placed in individual cages to prevent them from licking poison from the backs of one another. Two days later, decided reddening of the noses of four was noted. On the fourth day three rats died, and the next day the other three died. Post-mortem examinations failed to show any abnormalities.

This preliminary series of feeding experiments with the thallium grain and paste showed that wild and white rats died about three days after the consumption of comparatively small quantities of poisoned food. A series of experiments was then performed with chemically pure thallium compounds, to determine the nature of their action and the minimum lethal dose.

SERIES 2: CHEMICALLY PURE THALLIUM SULPHATE

A sample of chemically pure thallium sulphate was pulverized in a mortar and thoroughly mixed with screened rat food. Since thallium sulphate has the formula Tl_2SO_4 and contains 81 per cent of thallium, 1.24 grams of thallium sulphate were taken as the equivalent of 1 gram of thallium.

Seventy-two white rats, weighing between 103 and 197 grams, were fed specified doses of thallium as sulphate, December 4 to 17, 1924. Poisoned baits were consumed with the same eagerness as control food containing no thallium. In most instances all food was consumed within 15 to 30 minutes after exposure. The results obtained in this series of experiments are reported in Table 4. Twenty-five milligrams of thallium per kilo of body weight of rats (equivalent to 31 milligrams of thallium sulphate per kilo) killed 73 per cent of the rats tested. All doses of 35 milligrams per kilo or larger, or an increase of 40 per cent in dosage, killed all rats. A dose of 20 milligrams per kilo, or a decrease of 20 per cent in dosage, killed about a third of the rats tested. Accordingly, 25 milligrams per kilo was selected as the minimum lethal dose. Confirmation of this value was obtained in another series of feeding experiments on May 9, 1927. Fifteen rats weighing 125 to 175 grams were fed thallium baits. (Table 4.) With a minimum lethal dose of 25 milligrams of thallium per kilo when fed to rats, thallium proves to be more toxic than any of the ordinary rat poisons except strychnine.

TABLE 4.—*Toxicity of thallium as sulphate to white rats, 1924 and 1927*

EXPERIMENTS IN 1924

Dose of thallium per kilogram of body weight	Rats fed	Number of rats dying after—					Total deaths	
		1 day	2 days	3 days	4 days	5 days		
Mg.	*Number*						*Number*	*Per cent*
10	10						0	0
15	8		1				1	12
20	8		2	1			3	37
25	11		1	2	4	1	8	73
35	5		3	2			5	100
50	5			1	2	2	5	100
75	5			3	2		5	100
150	5		3	2			5	100
250	5	1	4				5	100
500	5	2	3				5	100
1,000	5	4	1				5	100

EXPERIMENTS IN 1927

20	5			1	2		3	60
25	5			1	4		5	100
30	5				5		5	100

It was noted that death usually occurred on the second or third day after feeding thallium bait, unless the quantity of poison taken was excessive. Ten times the lethal dose killed only one out of five rats within one day; 40 times the lethal dose killed only four out of five rats within one day. This would indicate that thallium must be absorbed from the gastrointestinal tract and localized within the tissues before producing death. For rats, at least, thallium is a definite poison, but not a rapid one.

Results obtained with the thallium-treated grain in series 1 suggested that the minimum lethal dose of the grain was 2.5 grams per kilo, or possibly somewhat less. Results obtained in series 2 showed that the minimum lethal dose of thallium as sulphate is 25 milligrams per kilo. Accordingly, it would appear that the grain fed contained 25 milligrams of thallium on 2.5 grams of grain, or 1 per cent of thallium. This has not been confirmed chemically. The exact lethal dose of the grain was not determined; it is conceivable that it might be lower than 2.5 grams per kilo, which would proportionately increase the thallium content. It appears safe to conclude, however, that the thallium-treated grain as fed contained at least 1 per cent of thallium.

SERIES 3: COMMERCIAL THALLIUM PREPARATIONS

Commercial supplies of thallium compounds were obtained by the Bureau of Biological Survey for use in controlling prairie dogs and ground squirrels in the West where strychnine baits had been refused by the rodents. It was soon found that some particular shipments of thallium products were rejected when mixed with the usual baits, although other lots were taken readily and effectively. A set of six samples was transmitted for examination and analysis

on November 25, 1927, representing acceptable and nonacceptable material employed by E. E. Horn, of the Biological Survey. His descriptions of these samples show the degree of success obtained in using them under field conditions:

Sample No. 1.—Taken from supply furnished during November, 1926. This material was absolutely refused when applied on steam-crushed oats at Flagstaff, Ariz., early in May, 1927. It was but slowly eaten at the Vallecito Ranger Station, Colorado (La Plata County, Zuni prairie dogs). It was slowly accepted by the Gunnison prairie dogs in Moreno Valley, N. Mex., during July, 1927, and was refused by Plains prairie dogs at Tatum, Lea County, N. Mex., during August, 1927. The trials at Tatum were under conditions of extreme summer heat. Acceptance in Moreno Valley, N. Mex., was slower than in a supply obtained by A. E. Gray and used during July, August, and September of the same year.

Sample No. 2.—From a supply furnished in April, 1926. During the spring of 1926 at Flagstaff, Ariz., this material was readily accepted and gave excellent results in controlling Zuni prairie dogs. In the spring of 1927 it was refused at Flagstaff, at Vallecito Ranger Station (Zuni prairie dogs), and in the Moreno Valley (Gunnison prairie dogs). In the summer of 1926 the material was a pure gray white, but in 1927 many yellowish flakes were noticeable in the product. This material was recieved and kept in a tin container.

Sample No. 3.—From a small supply received by the laboratory from S. E. Piper in California during September, 1927. No information is available here as to the source, but it is labeled "Thallium Sulphate—German production—thallium sulphate 99 per cent, inert material 15." This sample was received too late to be used for field tests of acceptability. Earlier German products were highly acceptable and of uniform toxic effect.

Sample No. 4.—A sample of thallous carbonate received during the late summer of 1926. It was highly acceptable to the Zuni prairie dogs at Flagstaff, Ariz., during August and September, 1926, and was readily taken by Gunnison prairie dogs in the Moreno Valley of New Mexico during a time when some of the sulphate salts were refused. At Tatum, N. Mex., during August, 1927, the carbonate was better accepted than the various sulphate samples, but was of too low acceptability to be of value. (Weather very hot. Extreme drought during part of tests, and summer rains occurring during the latter part of operations.)

Sample No. 5.—Thallous sulphate furnished to the Arizona district during the summer of 1926. This material was held over and used for the first time in the spring of 1927. Under prevailing spring winds refusal resulted. D. A. Gilchrist noted and reported an offensive odor in the material. This was removed by the American Smelting and Refining Co. chemists by heating to 150° C. for 30 minutes and placing in glass containers. After the spring winds subsided all baits were accepted with avidity.

Sample No. 6.—This sample has not been tried out in field operations but an analysis and feeding test are desired of it in order to ascertain its chemical purity, which would serve as a guide in possible future purchases of thallium sulphate.

Samples 1, 2, 4, and 5 came from one American manufacturer; sample 6 from another. Unsuccessful attempts were made to arrange for chemical analyses of these samples. Pressure of other work prevented feeding experiments until April 10, 1928, when doses of 20 and 40 milligrams of each sample were fed to three rats each. The rats ranged in weight from 145 to 355 grams. All baits were prepared to contain 0.5 per cent of thallium salt (0.4 per cent of thallium). Observations were continued over seven days, during which time all the rats died. (Table 5.) This prevents the accurate determination of the lethal doses of the respective samples. The fact, however, that all rats fed 20 milligrams per kilo died does prove that these samples were as toxic as the chemically pure thallium sulphate used in series 2.

TABLE 5.—*The toxicity of commercial thallium compounds to white rats*

Sample No.	Acceptance	Rats fed	Number of rats dying after period stated when fed 20 milligrams per kilo							Rats fed	Number of rats dying after period stated when fed 40 milligrams per kilo			
			1 day	2 days	3 days	4 days	5 days	6 days	7 days		1 day	2 days	3 days	4 days
		Number								*Number*				
1	Poor	3			1	1			1	3			2	1
2	do	3			1	1			1	3			3	
3	Unknown	3				1		2		3			2	1
4	Low	3		1	1	1				3			2	1
5	Ready	3			2	1				3			3	
6	Unknown	3		1	2					3		1		2

Of the 18 rats fed 20 milligrams per kilo, 14 consumed all their food within 15 to 20 minutes, 2 in about an hour, and the other 2 during the night. Of the 18 fed 40 milligrams per kilo, 12 finished eating within 15 to 20 minutes, 3 within an hour, and 3 during the night. No differences were noted in the acceptance of sample 1, which had a poor field acceptance, and of sample 5, which was readily taken in the field. Time until death was somewhat longer in this series than in the preceding tests, but too few animals were used to regard this as significant. Sample No. 6, an American product, appeared to kill as rapidly if not more so than the German sample, No. 3.

These feeding experiments failed to reveal any differences in acceptability or toxicity in the six samples studied. Further intensive feeding experiments would be needed upon several hundred rats to determine whether significant differences in time between feeding and death might be expected. It may be that rats are less susceptible to foreign odors or tastes than are prairie dogs, when poisoned baits are offered them; or the nature of the bait with which the poisons are mixed may be a contributing factor in the acceptance or rejection of specific lots of poisoned baits.

PHYSIOLOGICAL ACTION ON RATS

Rats appeared restless and uneasy 24 hours after the consumption of a fatal dose of thallium. Loss in appetite usually occurred, followed by respiratory distress, labored breathing, and death by respiratory failure. Post-mortem, the heart was engorged; the lungs and liver usually congested, and in some cases the kidneys and spleen; the stomach lining was hemorrhagic. Alopecia was not observed in the comparatively short time before death; surviving rats showed some losses of hair 10 to 15 days after feeding.

TOXICITY OF THALLIUM TO RABBITS BY INTRAVENOUS INJECTION

The quantity of thallium as chemically pure thallium sulphate that would kill rabbits was also determined. Aqueous solutions containing 0.5 to 1.0 per cent of thallium (5 to 10 milligrams of thallium per cubic centimeter, or 6.18 to 12.35 milligrams of thallium sulphate per cubic centimeter) were freshly prepared and injected into the

marginal ear veins of Belgian hares weighing 1,530 to 2,250 grams. Observations were made from time to time to determine the onset of poisoning symptoms and the occurrence of death. The results obtained are given in Table 6. The minimum lethal dose of thallium, as the sulphate, intravenously injected into rabbits is 25 milligrams per kilo of body weight. Identical results were obtained in the 1924 and 1927 experiments.

TABLE 6.—*Toxicity of thallium to rabbits*

Body weight	Dose of thallium injected, milligram per kilogram of body weight	Result	Body weight	Dose of thallium injected, milligram per kilogram of body weight	Result
2,250	10	Survived.	1,700	50	Died in 1 day.
1,800	25	Died in 1 day.	1,750	75	Do.
2,035	25	Died in 2 days.	1,530	100	Do.
2,220	25	Do.			

SUMMARY

LITERATURE

Thallium forms a series of stable, crystalline, water-soluble salts, most important of which are the acetate (CH_3COO–Tl) and the sulphate (Tl_2SO_4). Quantities as small as 0.002 milligram per liter (2 parts per billion) may be detected by the characteristic green line in the spectrum.

Thallium has a strong oligodynamic action on bacteria.

In acute poisoning in man or animals, marked interference with locomotion, paresis or paralysis of the lower posterior limbs, loss of appetite, decreased gastric acidity, emesis, diarrhea (which rapidly changes to obstinate constipation), a purple-blue line upon the gum margins, albuminuria, nephritis, marked respiratory depression, and death by asphyxia are noted. In general, the heart and circulation are not involved. Post-mortem, effusions of blood into the lungs, marked irritation of the gastrointestinal tract, and inflammatory proliferation of the mucosa of the esophagus and cardiac end of the stomach are recorded.

The lethal dose following administration has not been carefully determined but is approximately 0.5 milligram per mouse, 25 milligrams per kilo of body weight for rats, and 10 to 15 milligrams per kilo for dogs.

In chronic poisoning, reduction of vision, nephritis, pains in the muscles and sciatic nerves, general alopecia, disturbances of the endocrine glands, particularly the ovaries, testicles, thyroid, suprarenal, and pituitary glands, through action upon the central and sympathetic nervous systems, are reported. Cumulative action is established. Disturbances in calcium metabolism are reported to account for rickets and for checking growth. Thallium is slowly eliminated in the tears, milk, and urine, two to three months being required for complete elimination of medicinal doses. Human

beings exhibit the same symptoms as animals, alopecia being the most pronounced symptom.

Thallium has been abandoned for treatment of night sweats of phthisis because of its toxicity. Under carefully guarded conditions it may be of value in the production of alopecia in the treatment of ringworm in children, when doses of 8 milligrams per kilo of body weight are given under a physician's direction and observation. Toxic reactions are frequently obtained with a dose of this size or even smaller.

Information in the literature confirms the conclusion of Swain and Bateman (*141*) that "Thallium deserves to be classed among the most toxic of the elements."

LABORATORY EXPERIMENTS WITH RODENTS

By the standardized method developed for preparing and feeding poisons to rats, about 2.5 grams of a sample of commercial thallium-treated grain per kilo of body weight was found to kill wild and white rats in three to four days. Approximately 1 gram of a paste containing thallium caused death in the same time, when applied to the skin of the back. The minimum lethal dose of chemically pure thallium sulphate was found to be 25 milligrams of thallium, or 31 milligrams of thallium sulphate per kilo, when fed to rats. Death usually occurred on the second or third day. Six commercial thallium preparations were studied; some of them had been refused by prairie dogs in field tests, while other lots had been taken readily. All samples killed rats at 20 milligrams per kilo and were consumed with equal readiness.

Within 24 hours after consuming a fatal dose of thallium, rats became restless and lost their appetite, and difficulties in breathing developed, which terminated in death from respiratory failure. Post-mortem, congestion of the heart, liver, and lungs and sometimes of the kidneys and spleen was noted. Rats surviving sublethal doses of thallium showed alopecia 10 to 15 days after feeding.

Intravenously injected into the marginal ear veins of rabbits, 25 milligrams per kilo of thallium was found to be the minimum lethal dose.

CONCLUSIONS

Although thallium has been employed in human medicine in doses of 8 milligrams per kilogram of body weight, its use is dangerous and is decreasing.

The minimum lethal dose of thallium, fed as the sulphate to wild or to white rats, is 25 milligrams per kilogram of body weight.

Death usually occurs on the second or third day after feeding and is due to respiratory failure.

Thallium affects the sympathetic nervous system, thereby producing general alopecia (loss of hair), pains in the muscles and nerves of the legs, and disturbances of the endocrine glands (particularly the ovaries and testicles and the thyroid, suprarenal, and pituitary glands). Calcium metabolism is upset and leads to rickets.

Injected intravenously into rabbits, the minimum lethal dose is 25 milligrams per kilogram.

Thallium is among the most toxic substances recommended for rat control; comparative tests with other rat poisons by the same feeding method give the following minimum lethal doses:

	Mg. per kgm. of body weight
Thallium	25
Strychnine	20–25
Arsenious oxide	100
Red-squill powder	250
Barium carbonate	750

Thallium is a cumulative poison of high toxicity and is without taste, smell, or other warning property. It should not be recommended to the public as a rodent poison. Where the use of thallium is found necessary for the control of highly resistant species of rodents, it should be entrusted only to persons who understand its dangerous qualities and who will exercise appropriate care in handling it.

BIBLIOGRAPHY

(1) ANONYMOUS.
1927. TREATMENT OF RINGWORM WITH THALLIUM ACETATE. Jour. Amer. Med. Assoc. 89: 2217.

(2) ———
1929. TREATMENT OF RINGWORM OF THE SCALP BY THALLIUM. Brit. Med. Jour. (1929) 1: 214.

(3) ———
1929. MEDICINE AND THE LAW. OVERDOSE OF THALLIUM ACETATE: AN ERROR IN CALCULATION. Lancet 216: 795.

(4) ALTHOFF.
1928. SIEBEN FÄLLE VON THALLIUM-VERGIFTUNG IN EINER FAMILIE. Deut. Ztschr. Gesell. Gerichtl. Med. 11: 478–481.

(5) BAYER CO.
1925. METHODS FOR THE CONTROL OF RATS AND OTHER RODENTS IN THE UNITED STATES. [Mimeographed.]

(6) BEDFORD, G. V.
1928. DEPILATION WITH THALLIUM ACETATE IN THE TREATMENT OF RINGWORM OF THE SCALP IN CHILDREN. Canad. Med. Assoc. Jour. 19: 660–662, illus.

(7) BELEHRADEK, J., HUXLEY, J. S., and CURTIS, F. R.
1928. NOTE ON THE RELATION BETWEEN (A) EXTERNAL HYDROGEN ION CONCENTRATION AND (B) THALLIUM SALTS, AND THE RATE OF AMPHIBIAN METAMORPHOSIS. Biochem. Jour. 22: [63]–66.

(8) BETTMANN.
1901. ÜBER EXPERIMENTELLEN HAARAUSFALL DURCH THALLIUM ACETICUM. Dermatol. Centbl. 5: 2–6.

(9) BLAKE, J.
1890. DES RAPPORTS ENTRE LES SPECTRES DES ÉLÉMENTS ET LEURS ACTIONS BIOLOGIQUES. Compt. Rend. Soc. Biol. [Paris] (9) 2: [55]–58.

(10) BLYTH, A. W., and BLYTH, M. W.
1920. POISONS: THEIR EFFECT AND DETECTION. Ed. 5, thoroughly rev., enl., and rewritten, 747 p., illus. London.

(11) BRIEGER.
1927. THALLIUM-STRYCHNINVERGIFTUNG. Deut. Ztschr. Gesell. Gerichtl. Med. 10: [634]–637, illus.

(12) BULLARD, W. N.
1902. A CASE OF POISONING BY THALLIUM. Boston Med. and Surg. Jour. 97: 589–591. [Also published in Med. Surg. Rpts. Boston City Hosp. 13: 73–78.]

(13) BUSCHKE, A.
1900. EXPERIMENTELLER BEITRAG ZUR KENNTNISS DER ALOPECIE. Berlin. Klin. Wchnschr. 37: [1235]–1236.

(14) ———
1911. WEITERE BEOBACHTUNGEN ÜBER DIE PHYSIOLOGISCHEN WIRKUNGEN DES THALLIUM. Deut. Med. Wchnschr. 37: 161–163.

(15) BUSCHKE, A.
1923. UEBER DIE ANTIHYDROTISCHE WIRKUNG DES THALLIUM. Klin. Wchnschr. 2: 1698.
(16) ———
1927. THALLIUMEPILATION BEI HAARPILZERKRANKUNGEN. WEITERE BEOBACHTUNGEN UND ERFAHRUNGEN. Med. Welt 1(20): 234–236.
(17) ———
1928. ÜBER EXPERIMENTELLE UND KLINISCHE VERSUCHE ZUR ENTGIFTUNG DES THALLIUMS DURCH NATRIUMTHIOSULFAT. Dermatol. Wchnschr. 87: 1833–1834.
(18) ———
1928. ÜBER GEWERBLICHE THALLIUMVERGIFTUNGEN. Med. Klin. 24: 1042–1044.
(19) ——— and BERMAN, L.
1927. ÜBER CHEMISCHE UND BIOLOGISCHE BEZIEHUNGEN ZWISCHEN THALLIUM UND BLEI. Klin. Wchnschr. 6: 2428–2429, illus.
(20) ——— and BERMAN, L.
1927. WEITERE UNTERSUCHUNGEN ÜBER DIE WIRKUNG VON METALLSALZEN AUF DEN BRUNSTZYKLUS DER MAUS. München. Med. Wchnschr. 74: 969.
(21) ——— CHRISTELLER, E., and LOEWENSTEIN, L.
1927. SCHÄDELKNOCKENVERÄNDERUNGEN BEI EXPERIMENTELLER CHRONISCHER THALLIUMVERGIFTUNG. Klin. Wchnschr. 6: 1088–1089, illus.
(22) ——— DUCHAN, G., and JOSEPH, A.
1928. ÜBER DIE ANWENDUNG DES NATRIUMTHIOSULFATS ZUR VERHÜTUNG DER KOMPLIKATIONEN BEI DER THALLIUMTHERAPIE. Dermatol. Wchnschr. 87: 1835–1837.
(23) ——— and JACOBSOHN, F.
1922. UNTERSUCHUNGEN ÜBER THALLIUMWIRKUNG. Deut. Med. Wchnschr. 48: 859–860.
(24) ——— JACOBSOHN, F., and KLOPSTOCK, E.
1925. UEBER DAS WESEN DER OLIGODYNAMISCHEN ANTIBAKTERIELLEN METALLWIRKUNG. Deut. Med. Wchnschr. 51: 595–598.
(25) ——— JACOBSOHN, F., and KLOPSTOCK, E.
1926. DIE BIOLOGISCHE BEDEUTUNG DER OLIGODYNAMISCHEN METALLWIRKUNG UND IHRE BEZIEHUNG ZUR HOMOOPATHIE. München. Med. Wchnschr. 73: 437–438.
(26) ——— KLOPSTOCK, E., and PEISER, B.
1924. BIOLOGISCH-CHEMISCHE UNTERSUCHUNGEN BEI EXPERIMENTELLER RATTENRACHITIS. Med. Klin. 20: 345–347.
(27) ——— and LANGER, E.
1927. DIE FORENSISCHE UND GEWERBL.-HYGIENISCHE BEDEUTUNG DES THALLIUMS. München. Med. Wchnschr. 74: 1494–1497.
(28) ——— LANGER, E., and PEISER, B.
1924. SCHLEIMHAUTVERÄNDERUNGEN BEI RATTEN DURCH TEEREINWIRKUNG. [By Buschke and Langer.] SCHLEIMHAUT-UND KNOCHENVERÄNDERUNGEN BEI RATTEN DURCH THALLIUMEINWIRKUNG. [By Buschke and Peiser.] Arch. Dermatol. Syph. 145: 192–197, illus.
(29) ——— LÖWENSTEIN, L., and JOEL, W.
1928. WEITERE HISTOLOGISCHE BEFUNDE BEI EXPERIMENTELLER CHRONISCHER THALLIUMVERGIFTUNG. Klin. Wchnschr. 7: 1515.
(30) ——— LÖWENSTEIN, L., and JOEL, W.
1929. DIE SPEZIFISCHEN UND UNSPEZIFISCHEN WIRKUNGEN DES THALLIUMS. Med. Klin. 25: 462–463.
(31) ——— and PEISER, B.
1922. ÜBER DIE ENDOKRINE WIRKUNG UND DIE PRAKTISCHE BEWIRKUNG DES THALLIUMS. Dermatol. Wchnschr. 74: 443–445.
(32) ——— and PEISER, B.
1922. DIE WIRKUNG DES THALLIUM AUF DAS ENDOKRINE SYSTEM. Klin. Wchnschr. 1: 995.
(33) ——— and PEISER, B.
1922. EXPERIMENTELLE BEOBACHTUNGEN ÜBER BEEINFLUSSUNG DES ENDOKRINEN SYSTEMS DURCH THALLIUM. Med. Klin. 18: 731–732, illus.
(34) ——— and PEISER, B.
1922. WEITERE EXPERIMENTELLE ERGEBNISSE ÜBER ENDOKRINE STÖRUNGEN DURCH THALLIUM (VERSUCHE AN KAULQUAPPEN). Klin. Wchnschr. 1: 2182–2184, illus.

(35) Buschke, A. and Peiser, B.
1923. Über schwere schleimhaut- und knockenveränderungen bei ratten durch experimentelle thalliumwirkung. Klin. Wchnschr. 2: 1458–1459.
(36) ——— and Peiser, B.
1923. Epithelwucherungen am vormagen der ratten durch experimentelle thalliumwirkung. Ztschr. Krebsforsch. 21: [11]–18. illus.
(37) ——— and Peiser, B.
1924. Experimentelle erzeugung rachitisähnlicher knockenveränderungen und ihre deutung im sinne einer organsystemerkrankung. Klin. Wchnschr. 3: 523–525, illus.
(38) ——— and Peiser, B.
1925. Versuche zur entgiftung des thalliums. Klin. Wchnschr. 4: 2444.
(39) ——— and Peiser, B.
1926. Thalliumalopecie und sinneshaare. Klin. Wchnschr. 5: 977–979, illus.
(40) ——— and Peiser, B.
1928. Über die beeinflussung der thalliumwirkung durch hormone. Dermatol. Wchnschr. 87: 1115–1117.
(41) ——— and Peiser, B.
1928. Alopecie. *In* Klemperer, G., and Klemperer F. Neuen Deutschen Klinik. p. 299–314. Berlin and Wien.
(42) ——— Peiser, B., and Klopstock, E.
1926. Ueber einen fall von akuter thalliumvergiftung beim menschen nebst weiteren beobachtungen bei der klinischen verwendung des thalliums. Deut. Med. Wchnschr. 52: 1550–1552.
(43) ——— Zondek, B., and Berman, L.
1927. Der hemmende einfluss des thalliums auf den brunstzyklus der maus. Klin. Wchnschr. 6: 683–685.
(44) Cascio Rocca, G.
1926. L'azione biologica del tallio. determinazione del calcio nel siero di sangue dei bambini tignosi e tricofitici trattati con acetati di tallio. Cultura Med. Mod. 5: 453–459.
(45) Castex, H.
1900. Contribution à l'étude toxicologique des sels de thallium et en particulier du sulfate. 53 p. Toulouse.
(46) Castillo, E. G. del.
1928. Suppression of estrual cycle in white rat, with sodium fluoride and with thallium. Compt. Rend. Soc. Biol. [Paris] 99: 1405.
(47) Cicero, R.
1919. Tratamiento de las tiñas por el acetato de talio. Rev. Puebla no. 8. [Reference in Lancet 212: 389; also in Arch. Dermatol. u. Syph. 150; 438.]
(48) Collo, P. G. dal.
1924. Il tallio e la sua azione biologica. Riforma Med. 40: 249–250.
(49) ———
1924. Lesioni renali nell' avvelenamento acuto da tallio. Sperimentale 78: [519]–526, illus.
(50) Combemale.
1898. L'acetate de thallium contre les sueurs nocturnes des phthisiques. [Reported by Huchard.] Bul. Acad. Méd. [Paris] (3) 39: 572–573.
(51) Cortella, E.
1928. Ricerche sulle alterazioni del sistema nervoso centrale nell' intossicazione da acetato di tallio. Gior. Ital. Dermatol. e Sifil. 69: [1167]–1176, illus.
(52) ———
1928. Nuovo contributo alle ricerche sulle alterazioni del sistema nervoso centrale nella intossicazione da acetato di tallio. Gior. Ital. Dermatol. e Sifil. 69: [1507]–1602.
(53) Crookes, W.
1861. On the existence of a new element, probably of the sulphur group. Chem. News 3: [193]–194.

(54) CROOKES, W.
1863. ON THE EXTRACTION OF THALLIUM ON A LARGE SCALE FROM THE FLUE DUST OF PYRITES BURNERS. Chem. News 8: 159–161.
(55) CURCI, A.
1895. RICERCHE SUPERIMENTALE SULL' AZIONE BIOLOGICA DEL TALLIO. Ann. Chim. e Pharmacol. 22: [395]–403, [441]–449, [481]–488.
(56) CURTIS, F. R.
1927. A NOTE ON EPILATION BY THALLIUM ACETATE. Lancet 212: 1290.
(57) DAVIES, J. H. T.
1927. THALLIUM ACETATE. Brit. Med. Jour. (1927) 2: 79.
(58) ——— and ANDREWS, M. C.
1927. A CASE OF THALLIUM POISONING. Brit. Med. Jour. (1927) 2: 1139–1140.
(59) DELGADO, M.
1927. ESTUDIOS ACERCA DEL ACETATO DE TALIO. Mex. Dept. Salubridad Pub. Bol. 1927, no. 1, p. [9]–30, illus. [Abstract under title Pharmacology of Thallium Acetate. Pharm. Jour. and Pharm. [London] (ser. 4, v. 65) 119: 297.]
(60) DEVANE, J.
1927. THE NEW METHOD OF EPILATION IN TINEA TONSURANS. REPORT ON FORTY-FIVE CASES OF EPILATION BY THALLIUM ACETATE. Med. Press and Circ. (n. s.) 124: 95.
(61) DIVELLA, M.
1926. DELLA PROPRIETÀ EPILATRICE DELL' ACETATO TALLOSO E SUA ETIOLOGIA (NOTA PREVENTIA). Gior. Ital. Dermatol. e Sifil. 67: 291–314.
(62) DIXON, W. E.
1927. THALLIUM. Roy. Soc. Med. Proc. 20: [1197]–1200.
(63) DOAN, M.
1899. INDEX TO LITERATURE OF THALLIUM. 1861–1896. Smithsn. Misc. Collect. v. 41, no. 1171, 26 p.
(64) DOWLING, G. B.
1927. THE TREATMENT OF RINGWORM OF THE SCALP BY THALLIUM DEPILATION. Brit. Med. Jour. (1927) 2: 261–263.
(65) ——— and KELMAN, R.
1927. TWENTY-FOUR CASES OF RINGWORM OF THE SCALP TREATED BY THALLIUM EPILATION. Lancet 212: 389–390.
(66) DRAPER, H.
1866. A TEXTBOOK OF CHEMISTRY FOR THE USE OF SCHOOLS AND COLLEGES. 507 p., illus. New York.
(67) [DRUMMOND, M.]
1927. TREATMENT OF RINGWORM BY THALLIUM ACETATE. Brit. Med. Jour. (1927) 1: 329–330.
(68) DUBREILH, W.
1898. ALOPÉCIE DUE A L'ACÉTATE DE THALLIUM. Jour. Méd. Bordeaux 28: 316; also in Bul. Soc. Anat. Physiol. Bordeaux 19: 150–151.
(69) EHRHARDT, K.
1927. DER EINFLUSS MÜTTERLICHER THALLIUMVERGIFTUNG AUF DIE NACHKOMMENSCHAFT. Klin. Wchnschr. 6: 1374–1375, illus.
(70) FANTON, E.
1927. RICERCHE SPERIMENTALI CON L'ACETATO DI TALLIO SUI CONIGLI. Clin. Ped. 9: 483–508.
(71) FASANI-VOLARELLI, F.
1920. RISULTATI DELLE IONIZZAZIONI TALLICHE SUL SISTEMA PILIFERO. RICERCHE SPERIMETALI ED ISTOLOICHE. R. Accad. Fisiocritici. 28. [Original not seen. Mitteilung under the title Ergebnisse von thalliumiontophorese hinsichtlich der haarpapillen und haarscheiden. Dermatol. Wchnschr. 74: 460. 1922.]
(72) FELDEN, B. F.
1928. EPILATION WITH THALLIUM ACETATE IN THE TREATMENT OF RINGWORM OF SCALP IN CHILDREN. Arch. Dermatol. Syph. 17: [182]–193, illus.
(73) FERRARI, A. V.
1929. SOPRA UN CASO DI CHERATOSI SPINULOSA SUCCESSIVA A TRATTAMENTO CON ACETATO DI TALLIO. Gior. Ital. Dermal. e Sifil. 70: [100]–111.

(74) FIRTH, S. J.
1927. TREATMENT OF RINGWORM BY THALLIUM ACETATE. Brit. Med. Jour. (1927) 1: 1097, illus.

(75) FLAMM, P.
1926. VARIAZIONE DELLA FORMULA LEUCOCITARIA NEI BAMBINI TIGNOSI E TRICOFITICI TRATTITI CON ACETATO DI TALLIO. AZIONE DEL TALLIO SULLE GHIANDOLE ENDOCRINE. Biochim. e Terapia Sper. 13: [27]–32.

(76) FRIDLI, R.
1929. FATAL THALLIUM POISONING, AND DETERMINATION OF THALLIUM IN CADAVERS AS THALLOUS IODIDE. Ber. Ungar. Phar. Gesell. 4: 43–49. [Abstract in Chem. Abs. 23: 1840.]

(77) FULD, J.
1928. UEBER THALLIUMVERGIFTUNG BEIM KINDE. München. Med. Wchnschr. 75 (pt. 1): 1124.

(78) GINSBERG, S., and BUSCHKE, A.
1923. UEBER DIE AUGENVERÄNDERUNGEN BEI RATTEN NACH THALLIUM-FÜTTERUNG (KATARAKT UND IRITIS) UND IHRE BEZIEHUNGEN ZUM ENDOKRINEN SYSTEM. Klin. Monatsbl. Augenheilk. 71: 285–399.

(79) GIOVANNINI, S.
1899. ZWEI FÄLLE VON ALOPECIE NACH DEM GEBRAUCH VON THALLIUM-ACETAT. Dermatol. Ztschr. 6: 695–703.

(80) GRANDEAU, L.
1864. SELS DE POTASSIUM, DE SODIUM ET DE RUBIDIUM. Jour. Anat. et Physiol. Norm. et Path. 1: 378–385. (Action toxique de thallium comparée a cella du plomb, p. 384–385.)

(81) GREVING, R., and GAGEL, O.
1928. POLYNEURITIS NACH AKUTER THALLIUMVERGIFTUNG. Klin. Wchnschr. 7: 1323–1325.

(82) HABERDA, A.
1928. GIFTMORD DURCH THALLIUM. Beitr. Gerichtl. Med. 7: 1–9.

(83) HALLOPEAU.
1898. [DISCUSSION OF PAPER BY JEANSELME.] Bul. Soc. Française Dermatol. Syph. 9: 376–377.

(84) HARTNACK, H.
1925. THALLIUM ALS GIFT UND ARZNEI. Berlin. Tierärztl. Wchnschr. 41: [49]–51.

(85) HECKE, F.
1928. DIE THALLIUMVERGIFTUNG UND IHRE HISTOLOGISCHEN VERÄNDERUNGEN BEI RATTEN. Arch. Path. Anat. u. Physiol. [Virchow] 269: [28]–44, illus.

(86) HERFS, A.
1924. UEBER DIE RATTENPLAGE UND DIE NEUEREN BEKAMPFUNGMETHODEN. Nachr. Landsw. Abt. Farbenfabriken vorm Bayer & Co. 3: [29]–33.

(87) HUNTER, R., and MORRIS, C.
1890. UNIVERSAL DICTIONARY OF THE ENGLISH LANGUAGE.

(88) JEANSELME, E.
1898. SUR LE MÉCANISME DE L'ALOPÉCIE PRODUITE PAR L'ACÉTATE DE THALLIUM. Ann. Dermatol. et Syph. (3) 9: 999–1002; also published in Bul. Soc. Française Dermatol. Syph. 9: 374–376.

(89) JONES, B.
1869. VITESSE DU PASSAGE DANS LES TISSUS ANIMAUX DE DIVERS SELS, SURTOUT ALCALINS. Jour. Pharm. et Chim. (4) 10: 261–265.

(90) KAPS, L.
1927. KRIMINELLE TÖDLICHE SUBAKUTE THALLIUM-VERGIFTUNG. Wiener Klin. Wchnschr. 40: 967–970.

(91) KEANE, P. M.
1929. AN OVERDOSE OF THALLIUM ACETATE. Lancet 216: 795.

(92) KEIL, A.
1902. UEBER DIE SOGENANNTE KÖRNIGE ENTARTUNG DER ROTEN BLUTKÖRPERCHEN BEI VERGIFTUNGEN. Arch. Internatl. Pharmacodyn. et Thér. 10: [121]–143.

(93) KOBERT, R.
1906. LEHRBUCH DER INTOXIKATIONEN. 2 v., illus. Stuttgart.

(94) LAMY, [A.]
1863. SUR LES EFFECTS TOXIQUES DU THALLIUM. Compt. Rend. Acad. Sci. [Paris] 57: 442–445; also in Jour. Pharm. et Chim. (3) 44: 285–288.
(95) LEIGHEB, V.
1928. RICERCHE SPERIMENTALI SULLA INTOSSICAZIONE DA TALLIO. Gior. Ital. Dermatol. e Sifil. 69: 960–982.
(96) LEVY, M.
1927. MEDEDEELINGEN BETREFFENDE EPILATIE DOOR THALLIUMACETATE. Nederland. Tijdschr. Geneesk. 71: 2611–2612.
(97) LEWIN, E. M.
1928. ZUR FRAGE DES THALLIUM ACETICUM. Arch. Dermatol. u. Syph. 154: [187]–189.
(98) [LOUSTE, JUSTER, and DRAMEZ.]
1928. THALLIUM ACETATE IN THE TREATMENT OF HYPERTRICHOSIS. Jour. Amer. Med. Assoc. 90: 397.
(99) LUBENAU.
1928. VERGIFTUNG MIT ZELIO-PASTE (THALLIUM-VERGIFTUNG). Ztschr. Med.-Beamte 41: 106–110.
(100) LUCK, W.
1891. BEITRÄGE ZUR WIRKUNG DES THALLIUMS. 79 p. Dorpat. (Inaug. Diss.).
(101) LÜHRIG, H.
1927. ÜBER EINEN VERGIFTUNGSFALL DURCH EIN THALLIUMPRÄPARAT. Pharm. Zentralhalle 68: [561]–562.
(102) LUTZ, G.
1928. DIE GIFTIGKEIT DER THALLOVERBINDUNGEN. Zentbl. Gewerbehyg. u. Unfallverhutung (n. F. 5) 15: 172–174.
(103) MAMOLI, L.
1926. AVVELENAMENTO CRONICO DA TALLIO ED ALTERAZIONI OCULARI. Sperimentale 80: [229]–250, illus.
(104) ———
1927. RICERCHE SUL MECCANISMO DI PRODUZIONE DELLA CATARATTA DA TALLIO. Ann. Ottamologia e Clin. Oculistica 55: 35–43.
(105) MARMÉ, W.
1868. RESEARCHES ON THALLIUM. [Reviewed by Richardson, B. W., in Report on Toxicology, Forensic Medicine, and Hygiene. Brit. and Foreign Medico-Chir. Review [London] 41: 254–256.]
(106) MATTEUCCI, E.
1927. SULLE LESIONI ARTICOLARI DA ACETATI DI TALLIO. Rinascenza Med. 4: 401–402, illus.
(107) MELLOR, J. W.
1924. A COMPREHENSIVE TREATISE ON INORGANIC AND THEORETICAL CHEMISTRY. v. 5, p. 406–479. London and New York.
(108) MEYER, J., and WILK, H.
1923. ZUR KENNTNIS DER THALLISULFATE UND DER THALLISELENATE. Ztschr. Anorgan. u. Allg. Chem. 132: [239]–259, illus.
(109) MEYER, S.
1928. CHANGES IN THE BLOOD AS REFLECTING INDUSTRIAL DAMAGE. Jour. Indus. Hyg. 10: 29–55.
(110) MRONGOWIUS, J., and DUCHAN, G.
1928. ZUR FRAGE DER VERMEIDUNG DER KOMPLIKATIONEN BEI DER THALLIUMTHERAPIE. Dermatol. Wchnschr. 87: 1834–1835.
(111) MUNCH, J. C.
1928. THE TOXICITY OF THALLIUM SULPHATE. Jour. Amer. Pharm. Assoc. 17: 1086–1093.
(112) NEUDA, P.
1928. HAARAUSFALL IM LATERALEN ANTEIL DER AUGENBRAUE. Wiener Klin. Wchnschr. 41: 482–484.
(113) OLIVIER, H. R.
1927. L'INTOXICATION CHRONIQUE PAR L'ACÉTATE DE THALLIUM. Compt. Rend. Soc. Biol. [Paris] 96: 164–166.
(114) OLMER, D., and TIAN, A.
1908. INTOXICATION PAR L'ACÉTATE DE THALLIUM. PRÉSENCE DU THALLIUM DANS LE LIQUIDE CÉPHALO-RACHIDIEN. Compt. Rend. Soc. Biol. [Paris] 65: 742–743.

(115) Ormerod, M. J.
1928. pharmacological and toxicological aspects of thallium. Canad. Med. Assoc. Jour. 19: 663–665.
(116) Pauchly, G.
1926. durch essigsaures thallium hervorgerufene alopezie an der kindlichen kopfhaut. Wiener Klin. Wchnschr. 39: 948–949.
(117) Paulet.
1863. expériences sur l'action physiologiques des sels de thallium. Compt. Rend. Acad. Sci. [Paris] 57: 494–495.
(118) Peter, G.
1926. die epilation mit thallium-acetic. oxydulat. Arch. Dermatol. u. Syph. 150: [438]–450.
(119) Peyri, A.
1928. en talio en el tratamiento de la tiñas. accidentes (mortales) y recidivas. Rev. Med. Barcelona 9: [12]–21, illus.
(120) Pöhlmann, A.
*1913. beiträge zur aetiologie der alopecia areata mit experimentelle untersuchungen über die thallium-alopekie. Arch. Dermatol. u. Syph. 114: 633–690.
(121) [Popenoe, C. H.]
1926. a new use for thallium compounds. Amer. Jour. Pharm. 98: 693.
(122) Pozzi, S., and Courtade, A.
1884. note sur le traitement de la syphilis par le thallium. Gaz. Méd. Paris (7) 55: 147–150.
(123) Proszt, J.
1928. über die massanalytische bestimmung geringer mengen von thallium. Ztschr. Analyt. Chem. 73: 401–404
(124) Rabuteau.
1874. effets toxiques du thallium. Gaz. Hebd. Méd. 11: 293.
(125) ———
1883. effets physiologiques comparés du thallium et du plomb. Jour. Ther. 10: 112.
(126) Redlich, F.
1927. [einen fall von akuter thalliumvergiftung.] Wiener Klin. Wchnschr. 40: 694.
(127) Richet, C.
1899. de la toxicité du thallium. Compt. Rend Soc. Biol. [Paris] (11) 1: 252–253.
(128) Ritter, H., and Karrenberg, C. L.
1928. ein kasuistischer beitrag zur frage der thalliumepilation. Dermatol. Wchnschr. 86: 434–438.
(129) Rube and Hendricks.
1927. gewerbliche thalliumvergiftung. Med. Welt 1: 733.
(130) Sabouraud, R.
1912. l'acétate de thallium contre le duvet chez la femme. Rev. Internatl. Med. Chir. Année 23: 322.
(131) ———
1929. sur le danger des pommades à l'acetate de thallium prescrites contre l'hypertrichose. Bul. Soc. Française Dermatol. et Syph. 36: 12–18.
(132) Saing de Aja, [A.], and Zuloaga.
1922. depilation mit thalliumsalbe. (Fachzeitschriften.) Dermatol. Wchnschr. 74: 385.
(133) Schee, J.
1928. über den nachweis des thalliums in der organen kleiner durch "zelioweizen" vergiften tiere. Beitr. Gerichtl. Med. 7: [14]–31.
(134) Schneider, P.
1928. anatomische befunde bei thalliumvergiftung. Beitr. Gerichtl. Med. 7: [10]–13.
(135) Scovell, J. M. S.
1929. an overdose of thallium acetate. Lancet 216: 846.
(136) Seaston, A., and Wilson, C. R.
1927. thallium acetate depilation for ringworm of the scalp; its advantages and disadvantages. Brit. Med. Jour. (1927) 2: 263–264.

(137) SILVER, J.
1929. RAT CONTROL AIDED BY DEVELOPMENT OF EFFECTIVE NEW POISONS. U. S. Dept. Agr. Yearbook 1928: 518–521, illus.
(138) SOLLMANN, T.
1927. MANUAL OF PHARMACOLOGY AND ITS APPLICATIONS TO THERAPEUTICS AND TOXICOLOGY. Ed. 3, entirely reset, 1184 p., illus. Philadelphia and London.
(139) SPITZER, R.
1922. EXPERIMENTELLE BEITRÄGE ZUR KENNTNIS DER THALLIUMALOPECIE. Arch. Dermatol. u. Syph. 140: [429]–438, illus.
(140) STARKENSTEIN, E., ROST, E., and POHL, J.
1929. TOXIKOLOGIE, EIN LEHRBUCH FÜR ÄRZTE, MEDIZINALBEAMTE UND MEDIZINSTUDIERENDE. 531 p., illus. Berlin.
(141) SWAIN, R. E., and BATEMAN, W. G.
1910. THE TOXICITY OF THALLIUM SALTS. Jour. Biol. Chem. 7: 137–151.
(142) TELEKY.
1928. GEWERBLICHE THALLIUMVERGIFTUNG. Wiener Med. Wchnschr. 78: 506–508.
(143) TRUFFI, G.
1928. SULL' AZIONE BIOLOGICA DELL' ACETATO DI TALLIO. Bol. Soc. Ital. Biol. Sper. 3: [433]–434. [Abstract in Chem. Abs. 23: 2491.]
(144) VASSAUX, L.
1898. L'ACÉTATE DE THALLIUM EN THÉRAPEUTIQUE. 61 p., illus. Paris. (Inaug. Diss.)
(145) VIGNOLO-LUTATI, C.
1905. SULLE ALOPECIE SPERIMENTALI DA ACETATO DI TALLIO. Gior. Ital. Mal. Ven. della Pelle 46: [33]–50.
(146) WARD, J. C.
1930. THALLIUM POISONING IN SHEEP. Jour. Amer. Pharm. Assoc. 19: 556–559, illus.
(147) WIESEMANN, C.
1925. ERGEBNIS ÜBER DIE VERWENDUNG "ZELIO-GIFTKÖRNEN" FÜR DIE VERNICHTUNG VON MÄUSEN. Nachr. Landw. Abt. Farbenfabriken vorm Bayer & Co. 4: [29]–33.
(148) WIGGLEY, J. E. M.
1928. THE TREATMENT OF RINGWORM OF THE SCALP WITH THALLIUM ACETATE. Brit. Med. Jour. (1928) 2: 984.

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TECHNICAL BULLETIN No. 239 JUNE, 1931

A METHOD OF DETERMINING THE VOLUME AND TONNAGE OF HAYSTACKS

BY

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Bureau of Agricultural Economics

UNITED STATES DEPARTMENT OF AGRICULTURE - - - - - WASHINGTON, D. C.
IN COOPERATION WITH THE AGRICULTURAL EXPERIMENT STATIONS OF
CALIFORNIA, COLORADO, IDAHO, MINNESOTA, MONTANA, NEBRASKA
NEVADA, OREGON, SOUTH DAKOTA, AND UTAH

This bulletin contains information concerning the measurement of oblong stacks or ricks and of round stacks for the purpose of determining the volume and tonnage of hay in such stacks without actually weighing the hay. It includes comparisons between the rules for determining volume in use at present and a set of new formulas developed from the data collected as well as data on the number of cubic feet of hay required for a ton for various lengths of time from date of stacking to date of measuring. Much hay is sold by measure in the Western States, and any such information based on actual measurements and weights of a large number of stacks will be useful.

The study was carried on in cooperation with the agricultural experiment stations of California, Colorado, Idaho, Minnesota, Montana, Nebraska, Nevada, Oregon, South Dakota, and Utah. Thanks are due to the following persons who assisted in the work:

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A METHOD OF DETERMINING THE VOLUME AND TONNAGE OF HAYSTACKS

By W. H. HOSTERMAN,[1] *Associate Marketing Specialist, Division of Hay, Feed, and Seed, Bureau of Agricultural Economics*

In cooperation with the Agricultural Experiment Stations of California, Colorado, Idaho, Minnesota, Montana, Nebraska, Nevada, Oregon, South Dakota, and Utah

CONTENTS

	Page
Stack hay sales important but methods inaccurate	1
Reasons why hay is sold by measure	2
Popular measurement rules not based on research	2
Review of previous research	3
Cooperative investigations on stack measurements, 1927, 1928, and 1929	6
Objectives	6
Scope of work	7
Data collected	8
Problems presented for study	11
Volume of rectangular stacks	12
Studies on area of cross sections	12
Studies of cross-section areas by old rules	13
Formulation of new rules for determining cross-section area	16
Volume of round stacks	20
Studies on the determination of volume	20
Studies of the accuracy of old volume rules for round stacks	21
Formulation of new rule for determining volume of round stacks	24
Determination of cubic feet required for a ton	28
Stacks of various kinds segregated	28
Method of determining volume per ton	28
Cubic feet per ton	29
Variations in density	32
Need for additional research	34
Summary	35

STACK HAY SALES IMPORTANT BUT METHODS INACCURATE

Large quantities of hay have been bought and sold in the stack on a tonnage basis for many years. The parties interested in such transactions commonly agree on the quantity of hay in each stack by measuring it and then computing the volume and tonnage according to various rules that have been devised.

This method of marketing hay is followed extensively in the Pacific and Intermountain States and in the surplus-hay-producing areas of the Great Plains States. The cattlemen and sheepmen of these areas, who do not have a sufficient quantity of forage to feed their stock during the winter, often buy their supplies by measurement. Some stockmen do not have any meadow land, but follow a regular

[1] The author wishes especially to acknowledge the assistance received in the bureau from E. C. Parker and H. R. Tolley in outlining the work and reviewing the bulletin; and from W. J. Spillman, H. R. Tolley, and M. J. B. Ezekiel in the mathematical studies presented.

practice of driving their flocks and herds into the high mountain valleys or range lands for pasture in the spring and summer, and of driving the stock down again in the fall and wintering them on alfalfa stubble and on hay bought from the valley farmers.

Hay dealers purchase hay by this method in some areas, although this is not a general practice, because the dealer realizes that there is considerable variation in individual stacks and that the tonnage bought by measurement may not hold out by weight. Dealers learn also that some farmers put up their hay in a manner that will cause it to weigh out less than the average tonnage provided by the rule in use in that section. Farmers often discover, too, that if they build large, weather-resisting stacks, the hay may weigh out a greater tonnage than that provided by the rule commonly used.

REASONS WHY HAY IS SOLD BY MEASURE

One of the principal reasons why hay is sold by measure is that in many communities no scales are available to weigh the hay. Another reason is that the method of feeding the hay is sometimes such as to make weighing impracticable even though farm scales are available. Often the sheepmen or cattlemen make arrangements with the hay producers to pasture the meadows during the fall and winter and to feed the hay direct from the stack when snow covers the pasture, or when the pasture becomes so short that hay feeding is necessary. In such feeding operations the hay is either scattered direct from the stack with a short haul and consequent economy of labor, or feed racks are arranged about the stack so that the hay is not loaded on a wagon or sled. On the large farms and ranches, to load all hay and haul it to and from a wagon scale would often add an expense in the feeding operations that would be as great as any gains possible from buying weighed hay instead of measured hay.

In some sections in which the dealers purchase hay by measure the farmers are satisfied with the returns they receive. Where this custom is followed the dealer is often the operator of an alfalfa mill, who buys his season's hay supply from the farmers in the fall of the year, and who hauls the hay from the stack to the mill as it is needed. In the sections in which this method of selling hay is practiced, the farmer realizes that even though the estimate of tonnage determined by measurement is not so accurate as that determined by weight, it is preferable to use this estimate rather than await payment for several months until the hay can be weighed at the mill. Moreover, he runs no risk from damage that may occur to hay in the stack.

POPULAR MEASUREMENT RULES NOT BASED ON RESEARCH

The most popular measurement rules, such as the Frye-Bruhn, Quartermaster, and Outlaw rules, that have been in use for many years, are not based on the results of extensive research. Those who have used these rules have never known much about their accuracy for computing the volume of haystacks. These rules were born of necessity and were the outgrowth of a situation that required some method of determining the volume of haystacks to meet the practical conditions of hay marketing in the important hay and livestock States.

REVIEW OF PREVIOUS RESEARCH

Agricultural literature does not contain many references to rules for determining the volume of haystacks or the number of cubic feet required for a ton that were developed from research. The most important references are given herewith:

Spillman,[2] in 1905, referred to the rules now known as Outlaw and Frye-Bruhn rules and said that these rules are not accurate but give results 15 to 30 per cent less than the actual volume. He gave a rule in which height is one of the measurements required; but since this is very difficult to measure, the rule was never used extensively. He stated that it was a common custom to consider 512 cubic feet as a ton for hay that had been stacked only a few days and 350 to 380 cubic feet for hay that had stood two months or more.

The United States Department of Agriculture, during the years 1910 to 1912, carried on some investigations for the purpose of determining the number of cubic feet in ricks or stacks of hay and to determine the number of cubic feet required for a ton. The results of this study were published in 1913.[3]

In 1916 this material was revised, data relative to errors in measurement and rate of settling of hay in the stack were added, and a second publication was issued.[4] These department publications gave the formula $FOWL$ = Volume. In this formula O = over, W = width, L = length, and F some factor varying from 0.25 to 0.37, depending upon the height and fullness of the stack. For low, wide stacks the factor used was small (0.25); for tall stacks with full sides the factor was large (0.37). The cross-section drawings of nine stacks of different shapes were shown so that the factor to be used could be selected according to the shape of the stack measured.

These department publications also gave a method for determining the volume of round stacks. The method suggested divided the stack into several geometrical figures and then gave the formulas for determining the volume for each of these figures. In the formula the circumference was given instead of the diameter and a factor varying from 0.027 for cone-shaped stacks to 0.053 for dome-shaped stacks was given. When the stack had a distinct base with straight or sloping side walls, that portion was considered as a cylinder or frustum and a special formula was given therefor.

In connection with this study, 92 stacks were measured, and the hay was subsequently weighed for the purpose of determining the average number of cubic feet per ton. These data were obtained in the States of Virginia and New York and showed that timothy hay stacked less than 30 days required an average of 590 cubic feet for a ton. Hay stacked more than 30 but less than 60 days required 581 cubic feet per ton, and hay that was stacked more than 74 but less than 155 days required 515 cubic feet per ton. These figures were obtained on timothy and mixtures of timothy and clover and were not intended to be applicable to alfalfa or prairie hays.

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[2] SPILLMAN, W. J. FARM GRASSES OF THE UNITED STATES; A PRACTICAL TREATISE ON THE GRASS CROP, SEEDING AND MANAGEMENT OF MEADOWS AND PASTURES, DESCRIPTIONS OF THE BEST VARIETIES, THE SEED AND ITS IMPURITIES, GRASSES FOR SPECIAL CONDITIONS, ETC. 248 p., illus. New York and London. 1905.

[3] MCCLURE, H. B., SPILLMAN, W. J., and FROLEY, J. W. MEASURING HAY IN RICKS OR STACKS. U. S. Dept. Agr., Bur. Plant Indus. Circ. 131: 19-24, illus. 1913.

[4] ——— and SPILLMAN, W. J. MEASURING HAY IN RICKS OR STACKS, U. S. Dept. Agr., Off. Sec. Circ. 67: 10 p., illus. 1916.

Macpherson [5] reported a method of calculating the volume of oblong and round hay stacks:

For calculating the contents of oblong or square haystacks (Fig. 1) take the length and breadth of the stack in feet and inches halfway between the upper part of the stack bed and the eaves, A to B and B to C, an allowance (from 3 inches in trimmed stacks to 8 inches in others) being made in each measurement for the

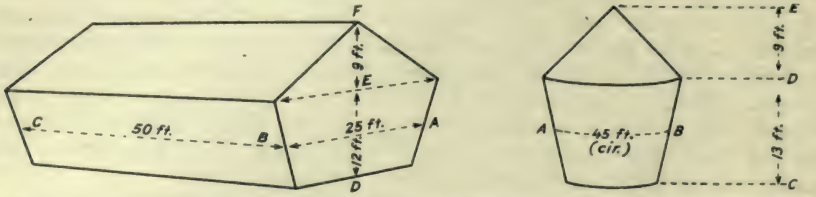

FIGURE 1.—Measurements taken in computing volume of haystacks. These are the measurements used by Macpherson for determining the volume of oblong and round stacks.

loose outsides; then take the height from the upper part of the stack bed to the eaves, D to E.

For stacks with gable ends take one-third of the perpendicular height of roof E to F.

For stacks with hipped ends take one-fifth of perpendicular height of roof.

EXAMPLES

Breadth of stack (A to B)	25 ft
Length of stack (B to C)	50 ft.
Height from upper part of stack bed to eave (D to E)	12 ft.
One-third of height from eaves to ridge (E to F) (9 ft.)	3 ft.
Total average height of stack	15 ft.

Contents of stack = length × breadth × total average height:—

25
50

1250
15

6250
1250
---
27)18750 cub. ft.
694.4 cub. yd. = contents of stack.

Having a stack fairly well settled, and weight per cubic foot 8.25 lb., this would give, according to table, 10 cubic yards to the ton. Therefore weight of hay in stack is 694.4 ÷ 10 = 69.44 tons.

To determine the number of cubic feet contained in a round stack with a conical top [fig. 1] the average girth must be measured at AB. The mean or average height is ascertained by taking the perpendicular height from the base of the stack to the eaves CD and adding to it one-third of the perpendicular height from the eaves to top DE.

[5] MACPHERSON, A. MEASUREMENT OF STACKS TO FIND WEIGHT OF CONTENTS. New Zeal. Jour. Agr. 20: 115–117, illus. 1920.

Multiply the average girth, 45 ft., by itself:—

```
                 45
                 ---
                 225
                180
                ----
                2025
Multiply the result by . 0795
                -----
               10125
              18225
             14175
             -------
             160.9875 sq. ft.
```

Multiply then by height C to D = 13 ft. plus one-third height of D to E = 3 ft. = 16 ft.:

```
  160.9875
        16
  --------
   9659250
  1609875
  --------
  2575.8000
```

If hay in stack is fairly well settled and weight per cubic foot 8.25 lb., this would give, according to table, 10 cubic yards to the ton, by which figure divide, as follows:—

```
27)2576 cub. ft.
10)95.4 cub. yd.
   9.5 tons.
```

The weight of hay per cubic yard in the stack depends on the nature of the hay, its age, the size of the stack, and the part of the stack taken. It varies from 112 lb. to 300 lb. per cubic yard. For different conditions of hay and stacks the number of cubic yards to a ton will approximately vary as follows:

Condition of Stack	Oblong or Square Stacks, Cubic Yards	Round Stacks, Cubic Yards
Not well settled	12 [324 cu. ft.]	13 [351 cu. ft.]
Fairly settled	10 [270 cu. ft.]	11 [297 cu. ft.]
Very compact	8 [216 cu. ft.]	9 [243 cu. ft.]

Second-cut clover hay will require 13 [351 cu. ft.] or 14 [378 cu. ft.] cubic yards to a ton.

The weight may be ascertained very accurately by actually measuring the cubic contents of a truss, and from this calculating the weight of a cubic foot.

McCarrol [6] says that the best method to determine the volume of hay stacks is by use of the prismoidal formula and gives illustrations of various-shaped stacks, the measurements that are necessary to determine the volume of these different-shaped stacks, and the constant multiplier that must be used for the different shapes.

He states that the number of tons of hay in a stack will vary with a number of factors: (1) size of stack; (2) age of stack; (3) condition of stack; (4) sort of hay; and (5) quality of hay.

[6] McCarrol, W. QUANTITY ESTIMATIONS ON THE FARM. Agr. Gaz. N. S. Wales 39: 696–699, illus. 1928.

The following table gives the number of cubic feet of hay of various kinds to the ton for various periods after completion of stacking, the figures being the results of actual experiments:—

Cubic Feet of Hay to the Ton

Period after stacking	Oaten		Wheaten		Lucerne
	Sheaf	Loose	Sheaf	Loose	
Immediately on completion of stack.	350	400	400	500	Varies greatly from 400 to 300 cu. ft. to the ton.
One week after	325	375	375	450	
One month after	300	350	350	400	
Twelve months after	300	325	350	400	

At Bathurst Experiment Farm, wheaten hay averaged 297 cubic feet to the ton, and loose straw 892 cubic feet to the ton. Any figure taken can only be approximate. The figures in the above table will serve as a guide and indicate that little or no settling takes place after the first month.

Rabate,[7] a French authority on methods of stacking hay and grain, gives rules for determining the volume of hay stacks. He gives rules for determining the volume of cone-shaped stacks, truncated cone-shaped stacks, and prismatic stacks. These are the usual mathematical formulas used for determining volume of such figures, except that the diameters are expressed in terms of the circumference because circumference of the stack is easily measured. Rabate also gives the following information relative to the weight of a cubic meter:

> The weight of the cubic meter is rather difficult to determine. It varies, not only with the kind of commodity stacked, but also with the duration of the settlement and the height of the stacks. It is greater in the lower layers or on the parts of the stack where the wagons have been unloaded. To determine the exact weight of the cubic meter in a hay or straw stack in distribution, measure the volume of a section of the stack, remove the section and weigh it. Ringelmann calculates the weight of a cubic meter of hay, in the case of sheaves pressed into stacks, as from 70 to 80 kilograms [457 to 400 cubic feet per ton]. Lefour and Wagner make it 90 to 100 kilograms [356 to 320 cubic feet per ton] in the case of hay in large stacks, firmly pressed down.

COOPERATIVE INVESTIGATIONS ON STACK MEASUREMENTS, 1927, 1928, AND 1929

OBJECTIVES

Farmers and stockmen for many years have called the attention of the United States Department of Agriculture to the importance of haystack sales by measurement, and to the fact that no accurate rule, which could be easily applied, for determining the volume of stacks has ever been developed. The many letters on this subject which the department receives indicate that it is a problem of wide spread importance in the important hay-producing States. In 1927, and at the instigation of one of the western alfalfa-producing States, a project was organized in the Bureau of Agricultural Economics to investigate

[7] RABATE, E. LES MEULES. Vie Agr. et Rurale Année 5 (13): 229–234, illus. 1915.

the problem and to determine, if possible, whether more accurate rules could be formulated than those heretofore developed.

A second purpose of these investigations was to check the rules in use at the present time for determining volume of hay stacks. As these rules are not based on the results of research their accuracy is doubted. If the investigational work should show such rules to be inaccurate the necessity for new rules would be apparent; or if one or more of these should be found accurate, their use could then be recommended.

The third purpose of these investigations was to determine the number of cubic feet required for a ton for different kinds of hay. Little work on this subject had ever been done. The work of the Department of Agriculture in 1910 to 1912 provided the only data available, and that gave information only for timothy and timothy and clover mixed hays on relatively small stacks. No data on the number of cubic feet of alfalfa or prairie hays required for a ton were available except figures used by the farmers; these were not the result of careful measurements and weights. It is in the sections in which these two hays are grown most generally that selling by measure is a common practice.

SCOPE OF WORK

The investigations were organized in cooperation with a number of the important hay States in which the sale of surplus hay by measure is a frequent practice. In many of these States the surplus hay can not be shipped out of the State either because of alfalfa-weevil quarantines or because high freight rates prevent marketing in the eastern part of the United States.

Data were obtained on stacks of alfalfa, timothy, timothy mixed, wild or prairie grass, and grain hays. The timothy mixed consisted of mixtures of timothy and clover, timothy and alfalfa, and timothy and wild or prairie grasses. In all cases timothy made up 50 per cent or more of the mixture. The wild or prairie hay consisted mainly of upland grasses, although a few stacks were mixtures of upland and cultivated grasses such as timothy and redtop. Because of the similar texture of these various grasses no attempt was made to segregate such mixtures into separate groups when the wild grasses made up over 50 per cent of the hay.

Most of the stacks were measured during the fall of 1927 and 1928, but in Colorado measurements and weights were obtained on a number of stacks each year from 1923 to 1928, and in Oregon data were obtained on stacks from 1919 to 1928.

A total of 1,932 rectangular stacks or ricks were measured. Many of these were measured from two to five times at approximately 30-day intervals to determine shrinkage while the hay remained in the stack. Six hundred and ninety-five round stacks were measured. All the stacks measured in Nebraska were round and a few round stacks were measured in Minnesota and Nevada. Few of the round stacks were measured more than once. A few of the field records had to be eliminated because of obvious errors, but 1,585 cross-section drawings of the ends of rectangluar stacks and 695 drawings of the round stacks were found to be free of errors and were used. Figure 2 shows the geographic areas in which the measurements were obtained and the number of stacks measured in each area.

Weights were obtained on 1,758 stacks of hay, of which 1,150 were rectangular and 608 were round. Many of these stacks were measured from two to five times so that 2,659 cases were used in the determination of the number of cubic feet per ton.

DATA COLLECTED

The data collected consisted not only of the various dimensions of the stack and the weight of hay at the time it was sold or fed, but also information about the kind of hay, cutting, method of stacking, maturity of hay when cut, texture, amount of rainfall from time of

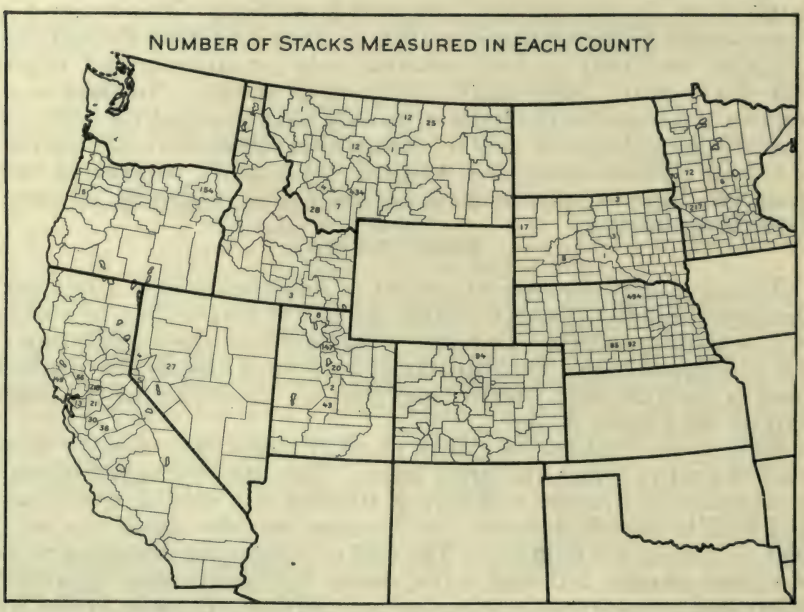

FIGURE 2.—Of the 2,627 stacks measured, 523 were located in California, 94 in Colorado, 3 in Idaho, 365 in Minnesota, 524 in Montana, 671 in Nebraska, 36 in Nevada, 159 in Oregon, 32 in South Dakota, and 220 in Utah

stacking to date of measurement, and any other obtainable facts that might be of value in tabulating the data.

DATA SHEETS

A uniform data sheet (fig. 3) was prepared by the department for the use of the field agents. On the reverse side of each sheet (fig. 4), a cross-section diagram was printed.

The cooperators were instructed to fill out a data sheet for each stack measured. The several dimensions for rectangular stacks were defined as follows:

Width.—The width of the stack is the distance between the lines at which the two sides meet the base. This dimension should be measured at the ground. It is a good plan to measure both ends of the stack and take an average of the two measurements. Width measurements should not follow the bows or contours of stack ends but along a straight line between two points, each point being where the side line of the stack meets the ground. In case the stack varies in width from point to point it is necessary to make allowance for such variations in determining the width, the allowance being a matter of judgment.

Length.—If the ends of the stack are straight up and down, measurement of the length of the stack is a simple matter. If the ends are somewhat sloping, as they frequently are, especially near the top of the stack, it is necessary to choose a point such that if the hay below it were cut off and used to fill in above, this hay would make the ends straight up and down. In most cases this point should be about one-third of the distance from the bottom to the top of the stack.

10133 DATA FOR STACK MEASUREMENT PROJECT 1928

Stack No. 2 (SE Stack)

State Utah District Salt Lake City

Farmer's name and address Thomas Doe, Doeville, R. F. D. #2.

Kind of hay Alfalfa Cutting First Date stacked June 15

Method used in building stack: Hand pitched Sleds

Kind of stacker Mormon derrick Fork or Slings

Stack exposed in wind or sheltered Exposed

Maturity of hay when cut 3/4 bloom

Texture: Coarse Medium Yes Fine

Measurements

	Approx. 30 days	Approx. 60 days	Approx. 90 days	Approx. 120 days	Approx. 150 days	Last time before weighing
Date Measured		Aug. 17	Sept. 20	Oct. 19	Nov. 20	
Height		19'	19'	19'	19'	
Width		25'	25'	25'	25'	
Length		34.5'	34.5'	34.5'	34.5'	
Over		54'	53'	53'	52'	
Over			53'			
Over						
Over						
Over						
Height to bulge						
Volume						

Date weighed Dec. 20 Weight or estimate of waste hay No waste

Weight of good hay 64,730 lbs. Total weight 64,730 lbs. - 32.3650 T

Degree of moisture: Tough Medium dry Yes Dry

Approximate amount of rainfall from time of stacking to date of each measurement
Precipitation from June 15 to November 20, 1928 - 4.14 inches.
Precipitation from June 15 to December 20, 1928 - 5.04 inches.
Other remarks: Well cured and stacked. 45% leaves. 75% color.

(See reverse side for diagram of stack cross section.)

FIGURE 3.—Copy of data sheet

Height.—About the best way to measure the height (fig. 5) of a stack is to stand a rod straight up as close to the end of the stack as convenient. Then stand at a distance of 15 to 20 feet from the stack and observe the point on the rod horizontally even with the top of the stack. Observing the height of the stack from the side rather than directly back of the measuring rod will give the most accurate measurements. A rod with the feet and half feet marked so as to be easily seen should be provided for this work.

Over.—The over of a stack is the distance from the ground on one side over the stack to the ground on the other side. If the stack is wider some distance above than at its base, care should be used to measure the over from the ground at the base of the stack rather than at a point directly under the widest part of the stack. In the case of long stacks where there is a possibility of variation in the over at various points in the stack, a number of over measurements should be made and recorded in the spaces provided on the data sheet.

Height to bulge.—The height to bulge is the distance from the ground to the widest portion of the stack. This measurement should be a perpendicular distance from the point of the bulge to the ground. If the height of the bulge varies several measurements should be made.

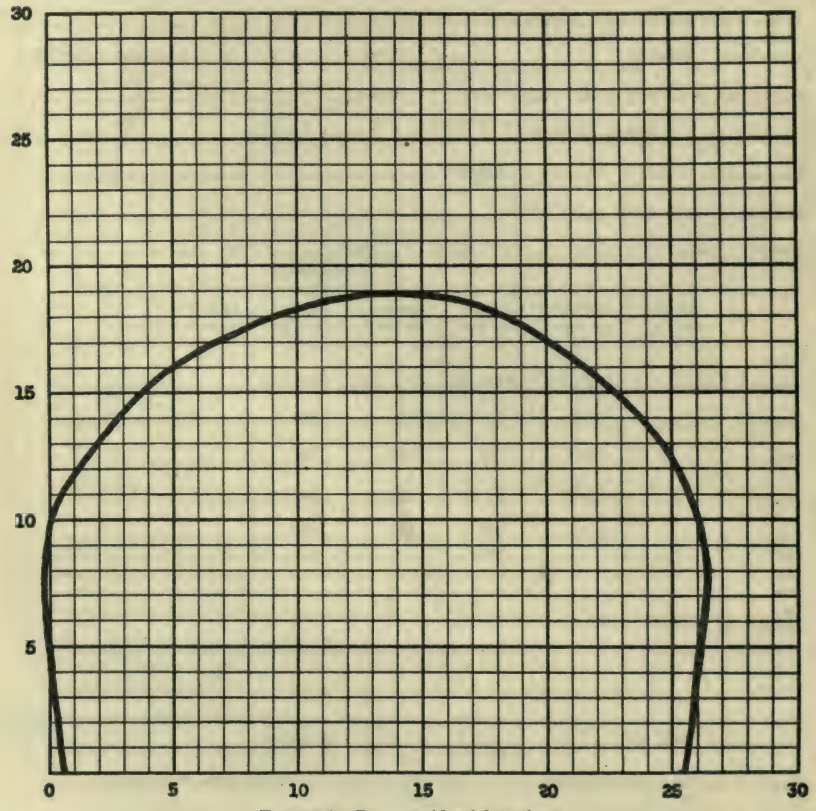

FIGURE 4.—Reverse side of data sheet

For round stacks the total height, height to the bulge, the circumference at the base, and the circumference at the bulge were the measurements taken. These measurements were defined as follows:

Height.—The height of the stack may be obtained by using the same methods as are used in determining the height of square or oblong stacks.

Height to bulge.—Height to bulge may be determined by using the same methods as for square or oblong stacks.

Circumference at base.—Circumference at base is the distance around the stack at the ground level. This measurement can be made with a long tape, care being taken to see that the tape is drawn in close to the stack at all points.

Circumference at bulge.—Circumference at bulge is the circumference at the widest part of the stack; care should be taken in all cases to prevent the tape from sagging, as this will result in an inaccurate measurement.

Over.—The over of a round stack is the distance from the ground on one side over the peak of the stack to the ground on the other side. Two overs at right angles to each other should be taken.

A cross-section drawing of each stack measured was made on the reverse side of the data sheet. This drawing was made to scale and was used as a check on the measurements taken, and for the purpose of determining the actual cross-section area of rectangular stacks and the actual volume of the round stacks. In other words, these cross-section drawings were the bases upon which was determined the accuracy of the various rules for computing the volume of both rectangular and round stacks.

METHOD OF COLLECTING DATA

Several methods were followed in collecting the field data. The project was organized on the basis that the States should collect the field data under the general direction of the United States Department of Agriculture and that the department should tabulate and summarize the data. In most of the States the data were collected by a State employee. These employees made the necessary contacts with the farmers, measured the hay, and obtained the weights or made arrangements for obtaining them. In several States the data were collected by reliable farmers or hay dealers under the general direction of State or Federal men. These cooperators were paid on the basis of the number of completed records turned in.

FIGURE 5.—Measuring the height of stacks. A rod marked in feet and half feet is stood up at one end of the stack. From a distance of 15 to 20 feet from the stack, the point on the rod horizontally even with the top of the stack is read. This gives the height of the stack

DIFFICULTIES ENCOUNTERED IN OBTAINING WEIGHTS OF INDIVIDUAL STACKS

Considerable difficulty was encountered in obtaining the weights of hay in the stacks. In 1928 there was a very large hay crop. Much hay that was harvested and stacked with the idea of shipping it to market later in the season was never sold; or it was sold locally, and the weights were not obtained. Throughout the entire period of the investigations many stacks were measured on farms the owners of which intended to bale the hay, weigh it, and ship it to market, but the hay was subsequently sold in the stack by measurement, thus making it impossible to obtain weight data.

PROBLEMS PRESENTED FOR STUDY

Three distinct problems were presented for consideration when this study was begun: (1) Volume studies for rectangular stacks or ricks,

(2) volume studies for round stacks, and (3) studies covering the number of cubic feet of various kinds of hay required for a ton.

VOLUME OF RECTANGULAR STACKS

STUDIES ON AREA OF CROSS SECTIONS

Some method of determining the actual volume of the various hay stacks measured had to be devised in order to decide whether the rules for determining volume at the present time are accurate. It was decided that the most practicable method for checking the old rules was to use the area of the cross-section drawing of each stack as the basis for comparison. The drawing of the cross section of the stack might not be absolutely accurate, but it would give the general contour of the stack.

This outline drawing obtained in the field was checked by the field agent at the time the drawing was made by measuring the over of the outline drawing with a road or map tracer. If the result obtained by this instrument did not agree with the over obtained by the tape, the drawing was corrected or the field measurements were checked. The field men found the road tracer of considerable aid in the field work since it tended to check both the outline drawings and the field measurements.

All outline drawings made by the field agents were measured again by the author with the road tracer, and in those cases in which the over obtained by the road tracer did not agree with the actual over given on the data sheet, a correction in the cross-section area was made. The formula for making this correction was $A=\frac{O^2}{O_1^2}A_1$. (A equals correct area of cross section; A_1 equals the area of the outline drawing; O equals the actual over given on the data sheet; and O_1 equals the over of the outline drawing.) This formula was assumed to be sufficiently correct for this work since the outline drawing and the measurments of over and width might also contain an experimental error that could not be checked.

Another method for correcting the area of the cross section was followed by H. E. Murdock, of the Montana Agricultural Experiment Station. He redrew the outline drawing of each stack until the over of the outline drawing was equal to the actual over given on the data sheet. When he made this new drawing he increased the height of the drawing but retained the same general outline as that made in the original drawing. This method gave results similar to those obtained by the formula given above.

The actual area of the outline drawing of each individual stack was measured by a planimeter. The planimeter was so calibrated that 1 square inch was recorded on the planimeter scale as 0.1. Since 1 square inch on the data sheet was equal to 25 square feet on the actual stack, 1 square foot of the actual area of the stack represented 0.004 on the planimeter scale. Since the scale could be read in thousandths, and since each cross section was measured twice and required to check within 0.004, the actual area of the cross section was measured to within 1 square foot of its area. This measured area was then corrected according to the formula given in the preceding paragraph, and the corrected area was used as the basis of all future calculations.

STUDIES OF CROSS-SECTION AREAS BY OLD RULES

The two rules most commonly used at present for determining volume of haystacks are the Frye-Bruhn rule, or rule of two, and the Quartermaster rule. Several others are used occasionally; The Outlaw rule, the FOWL rule, and the mathematical or triangle rule. A description and a discussion of each of these rules are given in the paragraphs next succeeding. Table 1 shows the accuracy of the various methods for determining the cross-section area of a stack by some of the rules mentioned. The percentage range of accuracy by each of the methods is very wide. The accuracy of these rules was obtained by using the actual cross-section area of the stack as 100, and the results obtained by the various rules were expressed as percentages of this base. In all these rules W is a symbol for width, O for over, H for height, L for length, and F for a variable factor, depending on the size and shape of the stack.

TABLE 1.—*Comparative accuracy of rules now in use: Number of stacks and percentage of total falling into certain percentage ranges for each of four rules as obtained by computing the area of the cross section by each rule and comparing such area with the actual cross-section area*

Percentage range (actual=100)	Stacks measured and accuracy of measurements determined by the—							
	Frye-Bruhn rule $\frac{(O-W)W}{2}$		Quartermaster rule $\left(\frac{O+W}{4}\right)^2$		Outlaw rule $\frac{OW}{4}$		Triangle rule $\frac{1}{2}WH+SB$[1]	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
60 to 64.9					4	0.25		
65 to 69.9					37	2.33		
70 to 74.9	4	0.25			134	8.45		
75 to 79.9	49	3.09	1	0.06	285	17.98	1	0.06
80 to 84.9	525	33.12	2	.13	435	27.44	11	.69
85 to 89.9	837	52.81	153	9.65	353	22.27	126	7.96
90 to 94.9	165	10.41	597	37.67	184	11.61	390	24.64
95 to 99.9	3	.19	513	32.37	99	6.25	865	54.64
100 to 104.9	2	.13	211	13.31	28	1.77	153	9.67
105 to 109.9			69	4.35	13	.82	30	1.89
110 to 114.9			20	1.26	8	.51	5	.32
115 to 119.9			11	.70	3	.19		
120 to 124.9			6	.38	2	.13	2	.13
125 to 129.9			1	.06				
130 to 134.9			1	.06				
Total	1,585	100.00	1,585	100.00	1,585	100.00	1,583	100.00

[1] See text for derivation of SB.

THE FRYE-BRUHN RULE

The Frye-Bruhn rule, or rule of two, $\frac{(O-W)W}{2}L$, is mentioned several times in some of the older literature on the subject of measuring hay in the stack. Spillman[8] says that this is a common rule for determining the volume of a haystack. This rule is in common use throughout all of the Western States where hay in rectangular stacks is sold by measure. The theory upon which this rule was developed was that the cross section of the stack could be reduced to a rectangle by subtracting the width from the over and then dividing the result by two to obtain the average height of the stack. The area of the

[8] Spillman, W. J. Op. cit.

cross section is then obtained by multiplying the width by this average height. This rule is on the statute books of at least two States (Montana and South Dakota) as the method for determining the volume of rectangular stacks, unless some other method of determining volume has been agreed upon previously.

The check made of the Frye-Bruhn rule shows that 96 per cent of the cases ranged between 80 and 95 per cent (Table 1) of the actual area, but that in a few cases this rule gave less than 75 per cent of the actual area, and in only two cases did it give an area equal to or greater than the actual area of the cross section. On an average this rule gave only 86.06 per cent (Table 2) of the actual area, therefore it gave a result that was about 14 per cent less than the actual area.

TABLE 2.—*Average percentage and average deviation for the Frye-Bruhn, Quartermaster, Outlaw, and Triangle rules as compared with the actual area*

State	Frye-Bruhn		Quartermaster		Outlaw		Triangle	
	Average percentage	Average deviation	Average percentage	Average deviation	Average percentage	Average deviation	Average percentage	Average deviation
California	88.13	±11.87	99.23	±5.58	87.39	±14.04	92.24	±8.02
Idaho	86.82	±13.18	92.41	±7.59	79.23	±20.77	96.23	±3.77
Minnesota	85.77	±14.23	97.04	±4.32	85.46	±14.62	97.68	±2.77
Montana	84.66	±15.34	95.48	±5.47	84.30	±15.78	97.39	±4.00
Nevada	87.58	±12.42	91.62	±8.41	76.04	±23.96	95.64	±4.40
Oregon	84.11	±16.45	97.41	±4.99	87.10	±13.31	96.57	±4.95
South Dakota	83.11	±16.89	96.59	±5.52	85.76	±15.01	94.38	±5.02
Utah	86.99	±13.01	92.08	±8.10	76.99	±23.01	95.69	±4.42
All States	86.06		96.19		84.17		95.96	

THE QUARTERMASTER RULE

The Quartermaster rule, $\left(\frac{O+W}{4}\right)^2 L$, known in some localities as the Government rule, was probably developed by the Quartermaster Department of the United States Army and was used by that department for determining the volume of haystacks or ricks in the purchase of forage for Army posts on the frontier many years ago before the department was able to purchase forage supplies by weight. This rule is based on the theory that the area of the cross section of the stack is equal to the area of the cross section of a square with sides equal to one-fourth of the perimeter of the stack (over plus width divided by 4).

The check made of the Quartermaster rule shows that 83 per cent of the cases ranged between 90 and 105 per cent (Table 1) of the actual area. The fact that for some types of stacks this rule gave less than 85 per cent of the actual area and for others gave over 125 per cent of the actual area, indicates that this rule gives very inaccurate results in some cases. On an average the Quartermaster rule gave 96.19 per cent (Table 2) of the actual area of the cross section of the stack.

THE OUTLAW RULE

The Outlaw rule, $\frac{OW}{4} L$, (also called the New Mexico rule) has been used for many years. At one time it was on the statutes of the

State of New Mexico as the legal method to be used for determining the volume of rectangular haystacks. This rule is based on the theory that the area of the cross section of the stack is equal to one-half the area of the cross section of a triangle which has a base equal to the width of the stack and an altitude equal to half the over of the stack.

The check made on the Outlaw rule shows that 79 per cent of the cases ranged between 75 and 95 per cent (Table 1) of the actual area. The average percentage of accuracy for this rule was 84.17 per cent. (Table 2.) This rule is the most inaccurate of all the rules in use at present and should never be used for determining the volume of a haystack.

THE FOWL RULE

The "Fowl" rule, FOWL, was developed by the United States Department of Agriculture and is a modification of the Outlaw rule. Instead of using a constant factor of 0.25, as is done in the case of the Outlaw rule, a variable factor ranging from 0.25 to 0.37 was used. The factor used depended upon the size and fullness of the stack. As an aid in determining which factor to use, cross sections of nine stacks of different shapes were illustrated, and the factor for each shape was given.

The accuracy of the FOWL rule could not be determined. An attempt was made to divide the stacks into the nine types illustrated in Circular 67,[9] but many stacks were found that did not conform to any of these nine types; others that closely resembled some of the types were of such shape that it was impossible to decide which factor should be used. For this reason the accuracy on a percentage basis was not calculated. The value of the factor F was calculated for each stack and found to vary from 0.19 to 0.38. The fact that it was very difficult to classify the outline drawings according to the nine shapes given in Circular 67 indicated that it would be unwise to recommend this method for use in determining the volume of hay stacks.

RULES REQUIRING HEIGHT MEASUREMENT

Several other rules based on mathematical formulas have been suggested from time to time, but they have always been so complicated that they were impracticable for use. Such formulas require the use of a height measurement which is extremely difficult to make. One of these formulas, the Triangle rule $(\frac{1}{2}\ WH+SB)L$, was studied to find what results were given by rules in which height was necessary. By this rule the cross section area of the stack is divided into three triangles, and the areas of these are determined. The area of one triangle is obtained by the formula, $\frac{1}{2}\ WH$. The other two triangles are equal and the area is obtained by the formula SB. In this formula $S=\sqrt{(\frac{1}{2}\ W)^2+H^2}$ and $B=\sqrt{(\frac{1}{4}\ O)^2-(\frac{1}{2}\ S)^2}$.

The check made of the Triangle rule shows that 79 per cent of the cases ranged between 90 and 100 per cent (Table 1) of the actual area. The average percentage of accuracy was 95.96 per cent (Table 2). This rule is the most accurate of any of the four rules studied but can not be recommended for popular use because it is very complicated to calculate and because a height measurement is necessary, which is difficult to obtain with accuracy.

[9] McCLURE, H. B., and SPILLMAN, W. J. Op. cit.

FORMULATION OF NEW RULES FOR DETERMINING CROSS-SECTION AREA

Consideration was given to a method for accurately determining the area of the cross section of haystacks that would use only the two most easily obtained measurements, namely, width and over. An attempt was made, therefore, to find an accurate expression of correlation between the area of the cross section and these two measurements. In the belief that there should be some definite correlation between these three known factors, several different correlations were formulated and studied. A correlation between the area and the over divided by the width was tried. This study showed a fairly definite average correlation, but several extremes of variation appeared, which indicated that there was no dependable degree of correlation. A second study was made in which the area divided by the width, was plotted against the over divided by the width. This correlation was based upon the same theory as the Outlaw rule, and it was thought that probably factors could be determined which would give a higher degree of accuracy than that obtained by the constant factor 0.25. This plan gave a fairly definite average correlation, but, as in the first case, wide extremes of variation appeared.

A third study was made in which the area divided by the square of the width was plotted against the over divided by the width, thus making both linear values. This correlation was based upon the same theory as the Frye-Bruhn rule, and it was believed that values could be determined to take the place of the divisor 2 used in this rule that would give more accurate results than the old rule. This method gave a very definite correlation with no wide variations, and a preliminary regression line was calculated on the data from each State.

The equations for these regression lines for each State were then computed, using the formula:

$$y = na + bx$$
$$xy = ax + bx^2$$

The values of a and b in the equation for the various States were as follows:

California	$a = -0.524$, $b = +0.546$.
Idaho	$a = -0.566$, $b = +0.5714$.
Minnesota	$a = -0.4371$, $b = +0.51028$.
Montana	$a = -0.4469$, $b = +0.5192$.
Nevada	$a = -0.4895$, $b = +0.538$.
Oregon	$a = -0.4618$, $b = +0.5333$.
South Dakota	$a = -0.4549$, $b = +0.5246$.
Utah	$a = -0.4818$, $b = +0.5340$.

The values of a and b given above are similar for the States of Montana, Minnesota, and South Dakota, where the low, round-topped stacks (fig. 6) are the general type. The values of a and b are similar for the States of Nevada, Oregon, and Utah where the high, round-topped stacks (fig. 7) are the usual type built. The values of a and b for Idaho are only tentative because only three stacks were used in determining the equation of the regression line.

The values of a and b for the California stacks seemed to be distinctly different from those of other States. Most of the California stacks were square and flat-topped. When the formula obtained

from the data from a given State was applied to determine the cross-section area of the stacks measured in that State, some percentage

FIGURE 6.—Low, round-topped stack of alfalfa hay

variations of from 10 to 15 per cent were found. This indicated that the formula for that State did not give the correct value of the cross-

FIGURE 7.—High, round-topped stack of the type built in the valleys of Utah, Nevada, and Idaho

section area for certain stacks in the State. Upon examining the cross-section drawings of these stacks it was observed that those that

had a large percentage of error were of different shape from those that made up the bulk of the cases in that State.

In some cases there was a considerable difference between the values for a and b, as, for instance, in California and Montana, whereas for Montana and Minnesota there was no difference. Upon examining the cross-section drawings for a number of these stacks, it was decided to separate the stacks into three groups (fig. 8), as follows: (1) Low, round-topped stacks of the type built commonly in Montana and Minnesota, or throughout the area where the overshot stacker is the usual type of stacker used, and which usually contain less than 10 tons of hay and often not over 5 tons; (2) high, round-topped stacks, with high side walls and well-rounded tops to shed water, of the type built in Utah, Nevada, Idaho, and Oregon, which usually contain 15 tons or more, and may in some cases contain 100 tons; and (3) square, flat-topped stacks, of the type built in certain parts of California that are not built primarily to shed water and are limited, therefore, to areas of very low rainfall.

Scatter diagrams (fig. 9) were then made in which each dot represented the relation between the ratio of over to width and the ratio

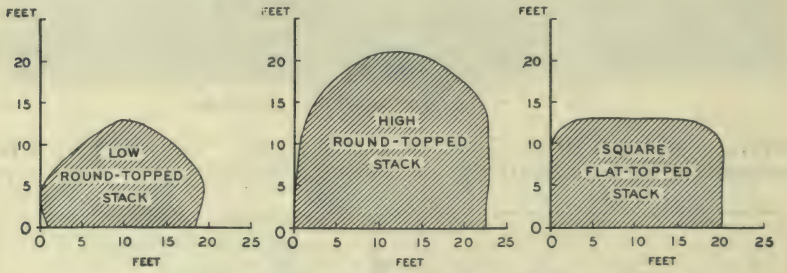

FIGURE 8.—Outline drawings of hay stacks of different shapes

of area of cross section to the square of the width for each individual stack. It is evident from these diagrams that a very high degree of correlation exists between these two factors when the stacks are separated into three groups according to their general shape. These diagrams also show the regression lines. New values for a and b were then calculated using the same equation as given above and the following formulas for determining the cross-section areas were developed for the three different shapes of stacks:

Low, round-topped stacks of the Minnesota and Montana type,

$$(0.52\times O)-(0.44\times W)W$$

High, round-topped stacks of the Utah and Nevada type,

$$(0.52\times O)-(0.46\times W)W$$

Square, flat-topped stacks of the California type,

$$(.056\times O)-(0.55\times W)W$$

The accuracy of these formulas is given in Table 3. This table shows that by these formulas a cross-section area may be computed

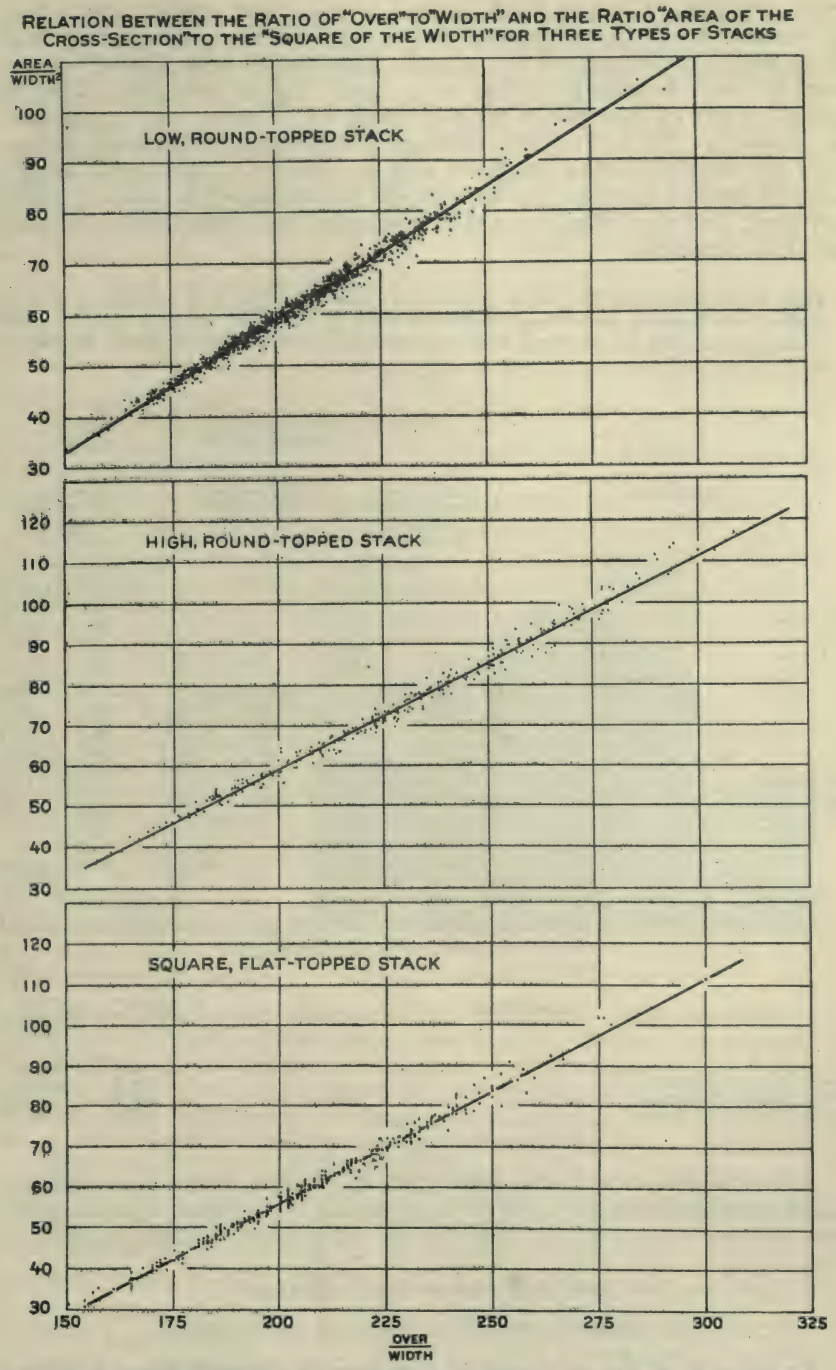

FIGURE 9.—This chart indicates a very high degree of correlation between these two ratios. Trend lines were fitted and mathematical formulas for determining the volume of each of the three types of stacks were developed

that is within 5 per cent of the actual cross-section area in practically all cases. In all three types of stacks the formulas gave results that were within 2 per cent of the actual cross-section area 63 to 67 times out of each hundred. This is a much higher accuracy than is given by any of the rules in use at present for determining the volume, as shown by Table 1. The average percentage and average deviation for these formulas are given also in Table 4. This table shows that all three formulas give an average percentage of a little over 100 per cent, and that the average deviation is less than 2 per cent for all three formulas.

TABLE 3.—*Accuracy of the factor method: Number of stacks and percentage of total falling into certain percentage ranges for each of the three types of stacks. The cross-section area of each stack was computed by the proper formula and compared with the actual cross-section area*

Percentage range (actual=100)	Stacks measured and accuracy of measurements determined for—					
	Low, round-topped stacks $(0.52\times O)-(0.44\times W)W$		High, round-topped stacks $(0.52\times O)-(0.46\times W)W$		Square, flat-topped stacks $(0.56\times O)-(0.55\times W)W$	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
92 to 92.9					2	0.60
93 to 93.9					1	.30
94 to 94.9	3	0.31			4	1.21
95 to 95.9	5	.52	9	3.08	10	3.02
96 to 96.9	44	4.57	17	5.82	18	5.44
97 to 97.9	100	10.40	27	9.25	27	8.16
98 to 98.9	173	17.98	46	15.75	40	12.08
99 to 99.9	202	21.00	54	18.49	54	16.31
100 to 100.9	144	14.97	45	15.41	75	22.66
101 to 101.9	124	12.89	40	13.70	43	12.99
102 to 102.9	84	8.73	22	7.53	29	8.76
103 to 103.9	40	4.16	12	4.11	19	5.74
104 to 104.9	23	2.39	14	4.80	3	.91
105 to 105.9	15	1.56	6	2.06	3	.91
106 to 106.9	5	.52			3	.91
Total	962	100.00	292	100.00	331	100.00

TABLE 4.—*Average percentage and average deviation for the formulas for rectangular stacks as compared with the actual area*

Type of stack	Average percentage	Average deviation
	Per cent	*Per cent*
Low, round-topped stacks	100.03	±1.66
High, round-topped stacks	100.04	±1.10
Square, flat-topped stacks	100.02	±1.52

These tables and charts show that the factor formulas constitute much more accurate methods of determining the volume of rectangular stacks than do any of the rules in use at present and are as easy to use.

VOLUME OF ROUND STACKS

STUDIES ON THE DETERMINATION OF VOLUME

To determine the accuracy of the various methods for measuring the volume of round stacks (figs. 10 and 11), some method of calculating the actual volume of the round stacks had to be worked out. Outline drawings of each round stack measured were made on the

reverse side of the data sheet. These drawings were checked by using the road tracer to measure the over of the outline drawing and thereby to ascertain whether the over of the drawing checked with the actual over of the stack measured in the field.

These measurements were checked again by the author when the data sheets were received for tabulation, and a correction factor was determined for each stack if the over of the outline drawing was not the same as the over obtained in the field. This correction factor was obtained by dividing the cube of the actual over by the cube of the over of the outline drawing.

The volume of a stack having a central-vertical-section figure similar to the drawing on the reverse side of the data sheet for that stack was then multiplied by this correction factor, and the result was used as the actual volume of the round stack. The correction formula may be represented as follows: $V=\frac{O^3}{O_1^3}V_1$. In this formula V equals actual volume of the stack; V_1 equals the volume of a figure having a central vertical section similar to the outline drawing; O equals the over as measured in the field; and O_1 the over of the outline drawing.

FIGURE 10.—Small round stack of the type built in Nebraska and Minnesota

Determination of the volume of round stacks presented some difficult problems, and the method that was used in this study may not give exact results, but it is the best that could be devised from the data that were obtained in the field. The field agents made outline drawings of each stack measured. These outline drawings showed the general contour and shape of the stack and were assumed to represent a vertical section taken through the center of the stack. The diameters of these outline drawings were measured at 1-foot intervals, and the volume of each of these frustums was determined. The sum of the volumes of the frustums gave the volume of a figure with a vertical section similar to the outline drawing. If the stack was peaked, the top part was considered as a cone instead of a frustum. The actual volume of the stack was then obtained by using the correction factor discussed above for that particular stack. This corrected volume was used as the basis for all future calculations.

STUDIES OF THE ACCURACY OF OLD VOLUME RULES FOR ROUND STACKS

The rules that have been used most commonly for determining the volume of round stacks are the Quartermaster round-stack rule and the so-called Prismoidal rule. These two rules are described and discussed in the two paragraphs next succeeding. In the formulas presented C is used as a symbol for circumference, O for over, H for height of frustum, and H_1 for height of part above frustum.

QUARTERMASTER ROUND-STACK RULE

The Quartermaster round-stack rule, $\left(\frac{C}{4}\right)^2 \times \left(\frac{O-\frac{C}{4}}{2}\right)$, is the most common rule in use at present for determining the volume of round stacks. This rule, also known as the Government rule, has been used in Nebraska for many years. The rule is based on the theory that the volume of a round stack is equal to the volume of a square stack one side of which is equal to one-fourth of the circumference of

FIGURE 11.—Large round stack of the Nevada type

the round stack, and whose average height is equal to one-half of the difference between the over and one-fourth of the circumference of the round stack.

The volume of each individual stack measured in the field was calculated by this rule. The accuracy of the rule was then ascertained by using as a base the actual volume obtained by dividing the stack into a series of frustums and calculating an accuracy percentage for each stack. Table 5 shows that 88 per cent of the cases fell between the 85 and 105 per cent range of accuracy, and Table 6 shows that this rule on the average gives 95.25 per cent of the actual volume. This table also gives the average deviation for this rule.

TABLE 5.—*Comparative accuracy of rules for determining volume of round stacks: Number of stacks and percentage of total falling into certain percentage ranges for each of three rules as obtained by determining the volume by each rule and comparing such volume with the actual volume*

Percentage range	Stacks measured and accuracy of measurements determined by the—					
	Quartermaster rule		Prismoidal rule		Chart method	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
40 to 44.9			1	0.16		
45 to 49.9			3	.48		
50 to 54.9			2	.32		
55 to 59.9			12	1.91		
60 to 64.9			13	2.07		
65 to 69.9			19	7.02		
70 to 74.9			43	6.85		
75 to 79.9	7	1.06	74	11.78		
80 to 84.9	19	2.87	72	11.46		
85 to 89.9	115	17.37	69	10.99	10	1.51
90 to 94.9	206	31.12	67	10.67	134	20.24
95 to 99.9	152	22.96	69	10.99	219	33.08
100 to 104.9	111	16.77	60	9.55	165	24.93
105 to 109.9	41	6.19	26	4.14	93	14.05
110 to 114.9	8	1.21	32	5.10	31	4.68
115 to 119.9	3	.45	24	3.82	10	1.51
120 to 124.9			13	2.07		
125 to 129.9			8	1.27		
130 to 134.9			4	.64		
135 to 139.9			4	.63		
140 to 144.9			5	.80		
145 to 149.9			3	.48		
150 to 154.9			3	.48		
155 to 159.9			1	.16		
160 to 164.9						
165 to 169.9						
170 to 174.9						
175 to 179.9			1	.16		
Total	662	100.00	628	100.00	662	100.00

TABLE 6.—*Average percentage and average deviation for the Quartermaster and Prismoidal rules and the Chart method for round stacks as compared with the actual volume*

Rule	Average percentage	Average deviation
	Per cent	*Per cent*
Quartermaster	95.25	±6.73
Prismoidal	91.55	±16.50
Chart method	100.03	±4.75

PRISMOIDAL RULE

The rule given in Circular 67[10] which is referred to throughout this publication as the Prismoidal rule was used also to determine the volume of each individual stack. The stacks were segregated into the several types necessary to determine the volume according to the diagram of shapes given in Circular 67, that is, cone shaped, half-sphere shaped, a shape intermediate between the cone and half-sphere shape, and each of these three shapes superimposed on a cylinder or a frustum in those cases in which the stack had a lower part with straight side walls, or the side walls had a distinct bulge. Some difficulty was encountered in segregating the stacks into these types because there were all gradations from the cone to the half sphere.

[10] McCLURE, H. B., and SPILLMAN, W. J. Op. cit.

The accuracy of this rule was calculated in the same way as for the Quartermaster rule. Table 5 shows that this rule gives a very wide range of accuracy, varying from less than 50 per cent to as high as 175 per cent of the actual volume, and only 35 per cent of the cases fell within 10 per cent of the actual volume. Table 6 shows that on the average this rule gives 91.55 per cent of the actual volume. This table also gives the average deviation for this rule.

FORMULATION OF NEW RULE FOR DETERMINING VOLUME OF ROUND STACKS

Much thought was given to the development of a rule or formula that would give satisfactory results for determining the volume of round stacks. It was recognized that farmers can obtain only two measurements with any degree of accuracy, namely, circumference at the base of the stack and over, and that a formula should be based, therefore, on these two measurements. In these investigations the over was taken twice, usually at right angles to each other, and the average was used as the actual over. The height of each stack was measured for this study but as considerable difficulty was encountered, it was concluded that height was not a practical measurement for use in determining volume.

A number of correlations were studied. The principal ones were: (1) Correlation between the volume divided by circumference and over multiplied by circumference, (2) correlation between the volume divided by circumference squared and the over, and (3) correlation between the volume divided by circumference cubed and over divided by circumference. The last correlation gave results that were practically as good as any method that was tried. The formula developed from this correlation is: $V=(0.04\times O)-(0.012\times C)C^2$. Various attempts were made to separate the stacks into groups that would give correlations more accurate than the average one, but none gave better results. This rule is based on the same theory as the Quartermaster rule, but the factors have been corrected so that the average percentage will be 100 per cent rather than 96 per cent. A logarithmic method was tried using the equation $\log V=\log a+b \log C+e \log O$, in which V is volume, a, b, and e are undetermined constants, C the circumference, and O the over. The above equation is merely the logarithmic form of the equation $V=AC^bO^e$. This method did not give results that could be used.

It was finally decided to try a graphic method for determining the volume. In this method the stacks were divided into groups according to given circumferences; that is, all stacks with 60 feet circumference were put together, those with 61 feet circumference, etc. The volume was then plotted against the overs for a given circumference, and preliminary trend lines were drawn. Readings for volume by circumference were then made on these trend lines and recorded for given overs. The volume was then plotted against the circumference for the individual over readings, and the final trend lines were drawn. From the last chart Table 7 was made. On this table the vertical axis was marked with the circumference and the horizontal axis with the over, the volume for a given circumference and over was read on the trend chart and recorded on the table where these two axes crossed. This table was made to cover stacks with circumferences ranging from 45 to 98 feet, and overs ranging from 25 to 50 feet.

The accuracy of this method was then calculated in the same way as for the Quartermaster rule; although it gives some variation, the results were more accurate than any of the other methods. Ninety-two per cent of the cases fell within 10 per cent of the actual volume, as shown by Table 5. Table 6 shows that on the average this method gives 100.03 per cent of the actual volume. This table also gives the average deviation.

TABLE 7.—*Volume of round stacks*[1] *of specified dimensions*

Circumference in feet	Indicated volume in cubic feet[2] when the over in feet is																									
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
45	825	960	1,090																							
46	840	975	1,105	1,235																						
47	855	990	1,120	1,250	1,385	1,505																				
48	870	1,005	1,135	1,265	1,400	1,525	1,650	1,785																		
49	885	1,020	1,150	1,285	1,420	1,540	1,670	1,805	1,935																	
50	900	1,035	1,165	1,300	1,435	1,560	1,690	1,825	1,955	2,090	2,215															
51	915	1,050	1,180	1,315	1,450	1,580	1,710	1,845	1,980	2,110	2,240	2,370	2,495													
52	930	1,065	1,200	1,330	1,465	1,600	1,730	1,865	2,000	2,130	2,265	2,400	2,530	2,665	2,795											
53	945	1,080	1,215	1,345	1,485	1,615	1,750	1,880	2,020	2,155	2,290	2,430	2,560	2,700	2,835	2,975										
54	960	1,095	1,230	1,360	1,500	1,630	1,770	1,900	2,040	2,180	2,320	2,460	2,595	2,735	2,875	3,015	3,160									
55	975	1,110	1,245	1,380	1,515	1,650	1,790	1,920	2,065	2,205	2,345	2,490	2,630	2,770	2,915	3,060	3,210	3,360	3,505							
56	990	1,125	1,260	1,395	1,530	1,665	1,810	1,940	2,085	2,230	2,375	2,520	2,660	2,805	2,955	3,105	3,255	3,415	3,565	3,720						
57	1,005	1,140	1,275	1,410	1,550	1,685	1,830	1,960	2,105	2,250	2,400	2,545	2,695	2,845	2,995	3,150	3,305	3,465	3,625	3,785	3,940					
58	1,020	1,155	1,290	1,435	1,565	1,705	1,850	1,980	2,125	2,275	2,425	2,575	2,725	2,880	3,035	3,195	3,350	3,515	3,680	3,850	4,010	4,175				
59	1,035	1,170	1,310	1,450	1,580	1,720	1,865	2,000	2,150	2,300	2,455	2,605	2,755	2,915	3,075	3,235	3,400	3,570	3,740	3,915	4,080	4,245	4,415			
60	1,050	1,185	1,325	1,465	1,600	1,740	1,885	2,020	2,170	2,325	2,480	2,635	2,790	2,950	3,115	3,280	3,445	3,625	3,795	3,975	4,150	4,320	4,490	4,670		
61	1,065	1,200	1,340	1,485	1,615	1,760	1,905	2,040	2,195	2,345	2,510	2,665	2,825	2,985	3,155	3,325	3,495	3,675	3,855	4,040	4,215	4,390	4,570	4,750	4,925	
62	1,080	1,215	1,355	1,500	1,635	1,775	1,925	2,060	2,215	2,365	2,535	2,695	2,855	3,020	3,195	3,365	3,540	3,730	3,915	4,105	4,285	4,465	4,650	4,830	5,015	5,200
63	1,095	1,230	1,370	1,515	1,655	1,795	1,945	2,080	2,235	2,390	2,560	2,725	2,890	3,055	3,235	3,410	3,585	3,780	3,970	4,165	4,355	4,540	4,730	4,910	5,105	5,295
64	1,110	1,245	1,385	1,530	1,670	1,810	1,960	2,100	2,260	2,415	2,585	2,755	2,920	3,090	3,275	3,455	3,635	3,835	4,030	4,230	4,425	4,615	4,805	4,995	5,195	5,390
65	1,125	1,260	1,400	1,545	1,685	1,830	1,980	2,120	2,280	2,440	2,615	2,780	2,950	3,125	3,315	3,495	3,680	3,885	4,085	4,290	4,490	4,690	4,885	5,075	5,285	5,485
66	1,140	1,275	1,420	1,560	1,705	1,850	2,000	2,140	2,300	2,465	2,640	2,810	2,985	3,160	3,355	3,540	3,730	3,935	4,145	4,355	4,560	4,760	4,960	5,160	5,370	5,580
67	1,155	1,290	1,435	1,575	1,720	1,865	2,020	2,160	2,325	2,485	2,665	2,840	3,015	3,195	3,395	3,585	3,780	3,990	4,205	4,420	4,630	4,830	5,040	5,245	5,460	5,670
68	1,170	1,305	1,450	1,595	1,740	1,885	2,040	2,180	2,345	2,510	2,690	2,870	3,050	3,230	3,430	3,630	3,825	4,045	4,265	4,485	4,695	4,900	5,120	5,330	5,550	5,765
69	1,185	1,320	1,465	1,610	1,755	1,905	2,055	2,200	2,365	2,530	2,715	2,900	3,080	3,265	3,470	3,670	3,875	4,095	4,320	4,545	4,760	4,970	5,195	5,415	5,640	5,860
70	1,200	1,335	1,480	1,625	1,770	1,925	2,075	2,220	2,385	2,555	2,745	2,930	3,115	3,300	3,510	3,715	3,920	4,150	4,375	4,610	4,825	5,045	5,275	5,495	5,730	5,955
71	1,215	1,350	1,495	1,640	1 790	1 940	2,095	2,240	2,405	2,580	2,770	2,960	3,145	3,335	3,550	3,760	3,970	4,205	4,435	4,670	4,895	5,120	5 355	5,580	5,820	6,050
72	1,230	1,365	1,515	1,660	1,805	1,960	2,115	2,260	2,430	2,605	2,795	2,990	3,175	3,375	3,590	3,805	4,015	4,255	4,495	4,735	4,965	5,195	5,435	5,665	5,910	6,145
73	1,245	1,380	1,530	1,675	1,820	1,975	2,135	2,280	2,450	2,625	2,825	3,015	3,210	3,410	3,630	3,845	4,065	4,310	4,550	4,795	5,030	5,270	5,515	5,750	6,000	6,240
74	1,260	1,395	1,545	1,690	1,840	1,995	2,150	2,300	2,470	2,650	2,850	3,045	3,245	3,445	3,665	3,890	4,110	4,360	4,610	4,855	5,095	5,340	5,595	5,835	6,090	6,335
75		1,410	1,560	1,705	1,855	2,010	2,170	2,320	2,495	2,675	2,875	3,075	3,275	3,480	3,705	3,935	4,160	4,415	4,670	4,915	5,165	5,415	5,675	5,915	6,180	6,430
76		1,425	1,575	1,725	1,870	2,030	2,190	2,340	2,515	2,695	2,905	3,105	3,310	3,515	3,745	3,975	4,205	4,465	4,725	4,980	5,235	5,490	5,750	6,000	6,270	6,525
77			1,590	1,740	1,890	2,050	2,210	2,360	2,540	2,720	2,930	3,135	3,340	3,550	3,785	4,020	4,250	4,520	4,785	5,045	5,305	5,560	5,830	6,085	6,355	6,620
78			1,605	1,755	1,905	2,070	2,230	2,380	2,560	2,745	2,955	3,165	3,375	3,585	3,825	4,065	4,300	4,570	4,840	5,105	5,370	5,635	5,910	6,170	6,445	6,715
79				1,775	1,925	2,090	2,250	2,400	2,580	2,765	2,980	3,195	3,405	3,620	3,865	4,105	4,345	4,625	4,895	5,170	5,440	5,710	5,990	6,255	6,535	6,810
80				1,790	1,945	2,105	2,270	2,420	2,605	2,790	3,010	3,225	3,440	3,655	3,905	4,150	4,395	4,675	4,955	5,235	5,510	5,785	6,070	6,340	6,625	6,905
81				1,805	1,960	2,125	2,285	2,440	2,625	2,815	3,035	3,255	3,470	3,690	3,945	4,195	4,440	4,730	5,010	5,295	5,575	5,855	6,145	6,425	6,715	7,000
82				1,820	1,975	2,145	2,305	2,460	2,645	2,835	3,060	3,280	3,500	3,725	3,985	4,240	4,490	4,785	5,070	5,360	5,645	5,930	6,225	6,510	6,800	7,090
83					1,995	2,160	2,325	2,480	2,665	2,860	3,090	3,310	3,535	3,760	4,025	4,280	4,535	4,830	5,130	5,425	5,715	6,005	6,305	6,595	6,890	7,185
84						2,180	2,345	2,500	2,690	2,880	3,115	3,340	3,570	3,795	4,065	4,320	4,580	4,885	5,190	5,485	5,785	6,080	6,385	6,675	6,980	7,280
85								2,520	2,710	2,905	3,140	3,370	3,600	3,830	4,105	4,365	4,630	4,935	5,245	5,550	5,850	6,155	6,465	6,760	7,070	7,375
86									2,735	2,930	3,170	3,400	3,635	3,865	4,145	4,410	4,675	4,990	5,300	5,615	5,920	6,230	6,545	6,845	7,160	7,470

87												3,195	3,430	3,665	3,900	4,185	4,455	4,725	5,040	5,360	5,680	5,990	6,300	6,620	6,930	7,250	7,565
88													3,460	3,700	3,940	4,220	4,500	4,770	5,090	5,420	5,745	6,060	6,375	6,700	7,015	7,340	7,660
89													3,490	3,730	3,975	4,260	4,540	4,815	5,145	5,475	5,805	6,125	6,450	6,780	7,100	7,430	7,755
90														3,765	4,010	4,300	4,585	4,860	5,200	5,535	5,865	6,195	6,525	6,860	7,185	7,520	7,845
91															4,045	4,340	4,630	4,910	5,250	5,595	5,930	6,265	6,600	6,940	7,270	7,605	7,940
92															4,080	4,380	4,670	4,955	5,305	5,650	5,995	6,335	6,675	7,020	7,355	7,695	8,035
93																4,420	4,715	5,005	5,360	5,710	6,055	6,400	6,750	7,095	7,440	7,785	8,130
94																4,460	4,760	5,050	5,410	5,765	6,120	6,470	6,825	7,175	7,525	7,875	8,225
95																	4,805	5,100	5,465	5,825	6,180	6,540	6,895	7,255	7,610	7,965	8,320
96																		5,150	5,515	5,885	6,245	6,610	6,970	7,335	7,695	8,055	8,415
97																		5,195	5,570	5,945	6,310	6,680	7,045	7,415	7,780	8,145	8,510
98																			5,625	6,000	6,370	6,750	7,120	7,495	7,865	8,235	8,605

[1] The volume of stacks that have circumferences or overs greater or less than those given in the table can be determined by using the formula, $V=(0.04\times O)-(0.012\times C)\ C^2$.
[2] Volumes given to the nearest 5.

DETERMINATION OF CUBIC FEET REQUIRED FOR A TON

STACKS OF VARIOUS KINDS SEGREGATED

The stacks for which weights were obtained were divided into a number of groups for the purpose of tabulating the number of cubic feet per ton. First they were segregated as to the kind of hay, such as alfalfa, timothy, and prairie. In those cases in which the hay was a mixture of several kinds it was grouped according to the kind of hay that predominated in the mixture. The stacks were divided into the following groups: Alfalfa, prairie, timothy and timothy mixtures, grass hay, and tame oat hay.

The timothy mixtures were mixtures of timothy and clover and timothy and wild grasses. The last-named mixtures were common in certain areas of Nebraska, Montana, and Minnesota where cultivated grasses, such as timothy and redtop, are sown in the native meadows to increase the yield and quality of the hay harvested. These cultivated grasses thrive only in those parts of the native meadows where there is plenty of moisture.

The grass hay was of two kinds: That produced in California which consisted mainly of wild oats, cheat, and bur clover; and that produced in South Dakota which was chiefly awnless bromegrass.

The stacks were divided also into groups according to the number of days from the time of stacking to the time of measuring. Many of the stacks were measured more than once, and therefore were placed in several groups according to the length of time in the stack. At first the stacks were divided into 5-day intervals, but these were later grouped into the following groups: 30 days and less, 35 to 60 days, 65 to 90 days, 95 to 120 days, etc.

METHOD OF DETERMINING VOLUME PER TON

For the purpose of determining the number of cubic feet per ton the volume of each stack was calculated by the formula applicable. For the low, round-topped stacks the rule $(0.52\times O)-(0.44\times W)WL$ was used; for the high, round-topped stacks the rule $(0.52\times O)-(0.46\times W)WL$ was used; for the square, flat-topped stacks the rule $(0.56\times O)-(0.55\times W)WL$ was used; and for the round stacks the volume was obtained from Table 7, which gives the volume for the various circumferences and overs.

The volume, as determined by these methods, was used in preference to the actual volume of rectangular stacks, as obtained by measuring the area of the cross section and multiplying it by the length of the stack, or of the round stacks, as obtained by calculating the volume of the 1-foot frustums, because there were many stacks for which cross-section drawings were not available upon which to base the actual volume, and thus the volume had to be figured from measurements only. The stacks that were measured at the Eastern Oregon Branch Experiment Station prior to 1927, and those measured at the Colorado Agricultural College had to be computed in this manner. Had the actual volume been used, a large group of valuable data could not have been used, or if used, would not be entirely comparable with the other data. Moreover, it seemed preferable to use the formulas for determining volume because the number of cubic feet per ton would then be based on the same method by which the volume would be determined in a practical application of the results of this study.

CUBIC FEET PER TON

The volume of each stack was then divided by the number of tons by weight to determine the cubic feet required for a ton of hay. These computations gave a wide range of results, indicating that there was a large variation in the density of the hay in the stacks. Table 8 shows the average number of cubic feet required for a ton of the various kinds of hay and the maximum and minimum number of cubic feet found in each group.

TABLE 8.—*Number of cubic feet per ton of principal kinds of hay in stack standing various periods*

Period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
ALFALFA				
30 and less	294	483	1,102	224
35 to 60	419	483	1,185	234
65 to 90	276	489	1,026	107
95 to 120	237	472	948	224
125 to 150	159	471	879	258
155 to 180	91	470	853	247
185 to 210	18	431	677	292
215 to 240	6	481	693	420
245 to 270	2	651	683	580
275 to 300	2	565	632	508
395 to 420	9	410	497	169
425 to 450	4	513	631	418
455 to 480	1	450	450	450
485 to 510	1	538	385	538
TIMOTHY AND TIMOTHY MIXED				
30 and less	39	757	1,195	433
35 to 60	75	644	994	319
65 to 90	67	624	929	410
95 to 120	26	633	912	474
125 to 150	12	600	797	547
155 to 180	3	716	805	680
WILD HAY				
30 and less	92	830	1,554	392
35 to 60	195	574	1,265	264
65 to 90	101	633	1,153	326
95 to 120	130	468	1,109	277
125 to 150	110	426	592	299
155 to 180	59	399	515	302
185 to 210	31	440	519	346
215 to 240	19	398	478	318
395 to 420	9	617	798	534

Table 9 shows by States the average number of cubic feet required for a ton of the various kinds of hay, as well as the maximum and minimum number of cubic feet. These figures indicate that differences in type of stack, method of stacking, and size of stack do not cause significant differences in the number of cubic feet required for a ton.

TABLE 9.—*Number of cubic feet per ton for different kinds of hay in stack standing various periods, by States*

ALFALFA HAY

State and period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
California:				
30 and less	174	443	597	224
35 to 60	118	424	596	259
65 to 90	22	392	555	209
95 to 120	1	224		
Colorado:				
30 and less	16	455	919	262
35 to 60	18	452	752	259
65 to 90	32	453	654	327
95 to 120	24	424	614	322
155 to 180	2	409	449	358
425 to 450	1	418		
Idaho:				
30 and less	3	669	731	573
65 to 90	2	651	673	620
125 to 150	1	547		
Minnesota:				
30 and less	10	835	1102	542
35 to 60	36	502	926	286
65 to 90	46	504	961	267
95 to 120	25	497	948	277
125 to 150	1	486		
Montana:				
30 and less	37	511	761	260
35 to 60	65	537	853	258
65 to 90	40	543	758	402
95 to 120	59	507	853	361
125 to 150	40	540	879	374
155 to 180	35	522	853	369
185 to 210	8	485	544	387
245 to 270	2	651	683	580
275 to 300	2	565	632	508
395 to 420	6	451	497	401
Nebraska:				
30 and less	6	328	392	288
35 to 60	19	374	557	254
65 to 90	24	450	1026	201
95 to 120	49	436	762	242
125 to 150	58	419	690	279
155 to 180	12	433	532	284
185 to 210	4	456	677	380
215 to 240	3	520	693	426
Nevada:				
30 and less	4	625	733	580
35 to 60	9	564	677	398
65 to 90	11	582	708	232
95 to 120	1	671		
125 to 150	2	556	649	411
Oregon:				
30 and less	11	527	774	397
35 to 60	78	512	1185	234
65 to 90	22	495	714	251
95 to 120	23	454	777	309
125 to 150	14	414	778	296
155 to 180	21	466	816	292
185 to 210	4	349	538	292
395 to 420	2	210	254	169
425 to 450	2	587	631	546
485 to 510	1	538		
South Dakota:				
30 and less	12	450	732	307
35 to 60	18	343	691	237
65 to 90	24	341	676	107
95 to 120	17	342	742	258
125 to 150	14	369	671	258
155 to 180	1	346		
Utah:				
30 and less	21	564	842	276
35 to 60	58	529	894	289
65 to 90	53	520	875	362
95 to 120	38	498	855	356
125 to 150	29	506	749	365
155 to 180	20	450	686	246
185 to 210	2	536	539	535
215 to 240	3	455	518	420
395 to 420	1	483		
425 to 450	1	464		
455 to 480	1	450		

TABLE 9.—*Number of cubic feet per ton for different kinds of hay in stack standing various periods, by States*—Continued

CLOVER HAY

State and period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
Minnesota:				
65 to 90	1	365		
Oregon:				
30 and less	2	769	800	732
65 to 90	2	718	758	672

GRASS HAY

California:				
35 to 60	128	658	926	429
65 to 90	11	533	587	488
South Dakota:				
30 and less	2	312	362	274
35 to 60	2	328	329	328
65 to 90	2	325	326	324
95 to 120	2	311	312	309
155 to 180	1	311		

PEAS AND BARLEY HAY

Oregon:				
35 to 60	1	602		
65 to 90	1	1,099		
95 to 120	1	578		
125 to 150	1	578		
155 to 180	2	722	943	582

SWEET CLOVER HAY

Minnesota:				
65 to 90	3	419	692	331

TAME OAT HAY

California:				
35 to 60	10	528	613	393

TIMOTHY

Minnesota:				
30 and less	9	983	1,195	772
35 to 60	12	832	994	695
65 to 90	9	799	929	672
95 to 120	1	883		

TIMOTHY MIXED

Minnesota:				
30 and less	6	833	972	640
35 to 60	12	628	837	319
65 to 90	7	636	750	474
95 to 120	7	650	912	474
Montana:				
30 and less	23	596	836	433
35 to 60	51	601	831	415
65 to 90	51	577	914	410
95 to 120	18	620	813	501
125 to 150	12	600	797	547
155 to 180	3	716	805	680

TABLE 9.—*Number of cubic feet per ton for different kinds of hay in stack standing various periods, by States*—Continued

WILD HAY

State and period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
Minnesota:	*Number*	*Cubic feet*	*Cubic feet*	*Cubic feet*
30 and less	58	965	1,554	392
35 to 60	56	840	1,265	588
65 to 90	50	781	1,153	566
95 to 120	20	738	1,109	541
395 to 420	9	617	798	534
Montana:				
30 and less	2	559	628	508
35 to 60	19	476	529	431
65 to 90	2	498	602	436
95 to 120	17	458	584	392
185 to 210	9	469	510	428
Nebraska:				
30 and less	32	487	490	417
35 to 60	120	428	610	264
65 to 90	49	428	522	326
95 to 120	93	411	510	277
125 to 150	110	426	592	299
155 to 180	59	399	515	302
185 to 210	22	423	519	347
215 to 240	19	398	478	318

The variation in the figures on the cubic feet per ton for the various kinds of hay shows the reason for the difference of opinion that has existed as to the number of cubic feet required for a ton. The hay dealers and stockmen have realized that there was considerable variation in density, even if they have had no accurate data to prove this idea. These average figures show that the 512 cubic feet per ton for alfalfa at the end of 30 days' settling, in use in many sections now, is fairly accurate. Table 8 shows also that stacks do not settle much after 30 days, and that the old figure of 422 cubic feet after 90 days' settling is too low. These figures show further that more cubic feet per ton are required for prairie hay than for alfalfa hay instead of less, as was generally supposed, and that the figures of 422 cubic feet per ton after 30 days' settling, and 343 cubic feet per ton after 90 days' settling, are entirely too low for prairie hay.

VARIATIONS IN DENSITY

A number of studies were carried on to find the reason for these variations in density, but the data obtained were not sufficiently comprehensive to provide a satisfactory explanation. Data obtained in Montana[11] on stacks in various parts of the State showed that there was considerable variation in the density of the hay. Samples (approximately 5 cubic feet in each instance) were taken from various parts of these stacks and weighed. (Fig. 12.) These samples were obtained by forcing the prongs of the hay sampler shown in Figure 13 into the hay and then cutting around the sample with a hay knife. When the sample had been cut loose on all sides, it was lifted out onto a canvas and weighed. (Fig. 14.) By this method a sample of hay was obtained that gave the approximate density of the

[11] These data were collected by H. E. Murdock, of the Montana Agricultural Experiment Station. The sampling device was devised by Mr. Murdock.

hay at that point in the stack. By taking several samples in various parts of the stack, the approximate average density was ascertained. Samples taken from the same general location in different stacks varied as much as 10 pounds, which was about a 50 per cent variation. This sampling method indicates that the variations in density, shown in Tables 8 and 9, are not due to errors in the weights given for the individual stacks, but to some undetermined cause.

Several theories as to the reason for these variations in the density of stacked hay have been presented, but no data to prove or disprove these theories have been collected. The theory that the moisture at time of stacking is an important factor in the density of the hay has much to recommend it. Hay with 20 to 25 per cent moisture at time of stacking is more pliable and is heavier per cubic foot than hay with

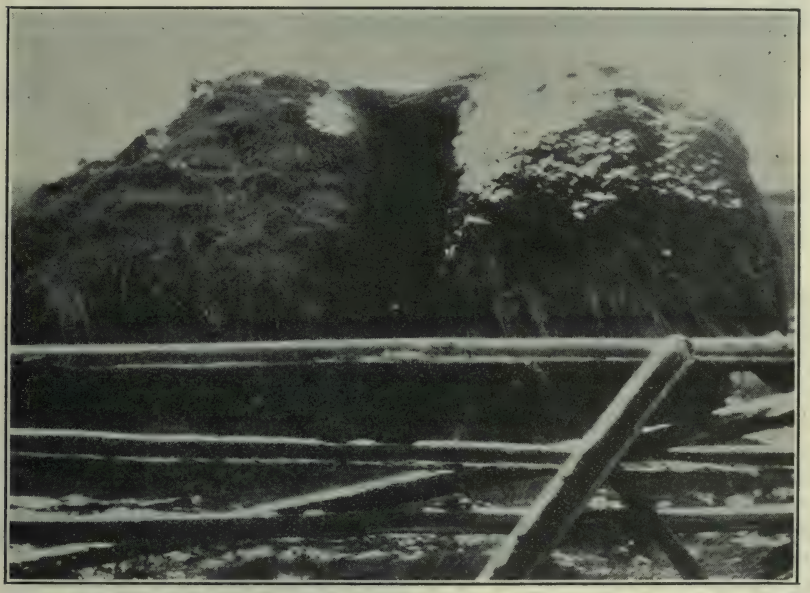

FIGURE 12.—Stack of hay that has been sampled for density. Samples were taken at various depths to determine the variation in density of the hay at different points and to determine the average density of the stack

only 12 per cent moisture, and therefore would settle more and become more compact. Observations made by the writer in the various hay-producing areas tend to support this theory. It is much easier to force the hand or a rod into a stack of hay made from overcured hay, especially alfalfa, than it is to force the hand or rod into a stack of hay that was stacked before the hay became overdry. The Montana data support this theory, because in several instances the hay was reported to have been stack sweated when the sample taken from the stack was much heavier than the average for the group of stacks sampled. Moreover, in several instances in which the sample taken was exceptionally light, it was noted that the hay was very dry and fluffy at the time of sampling.

Another factor that may influence density is the coarsness or fineness of the hay, or the quantity of hard, woody stems that do not collapse when weight is added. Hay that is overripe or that contains

large quantities of harsh and woody weeds probably does not settle so much as hay that has pliable stems or that is free of foreign material. Other factors may affect the density of hay in the stack, but the ones mentioned are probably the most important.

FIGURE 13.—Sampling device for determining the density of hay in the stack. The hay is cut away from around the frame to the depth of the prongs, then the hay knife is inserted under the central prongs and the sample lifted out and weighed

NEED FOR ADDITIONAL RESEARCH

A determination of the reasons for the variation in the number of cubic feet of hay required for a ton under different conditions is a problem that should receive additional study. Because of the conditions under which much hay is fed in many sections, it will continue to be sold by measure even if the interested parties realize that there is a large variation in the number of cubic feet required for a ton, and that this variation can not be measured in a practical way under existing rules.

Additional research should be carried on, therefore, in a few well-chosen localities where the various factors that influence the density of the hay can be measured and observations made which will explain the variations in density. Special attention should be given to the following factors: Percentage of moisture in the hay at the time of storing; texture and maturity of the hay; leafiness of the hay in the case of alfalfa and clover; and rate of settling during the first 30 days.

FIGURE 14.—Weighing the density sample of hay

A series of stacks were measured in California in 1928 to determine rate of settling, but because no common first measurement was given these data could not be tabulated.

Methods should be investigated for determining the density of stacks, either by taking samples from a definite place in the stack and then determining the average density of the stack from the sample, or by developing an instrument by means of which the density can be measured by the degree of resistance encountered upon thrusting the instrument into the stack.

It is only by such research that the reasons for the variation in density and shrinkage of hay in the stack can be found, that the number of cubic feet required for a ton under various conditions can be determined, and that satisfactory methods of selling hay by measure can be recommended.

SUMMARY

Much hay is sold annually by measure, especially in the Western States. Accurate rules for determining the volume of rectangular and round stacks and accurate information relative to the number of cubic feet necessary for a ton should be available.

The rules for determining volume of rectangular stacks in use at present are not very accurate. On an average the Frye-Bruhn rule gives only 86 per cent of the actual volume, the Quartermaster rule 96 per cent of the actual volume, and the Outlaw rule 84 per cent of the actual volume. All three of these rules have a wide range of error, in some cases giving only 70 per cent of the actual volume, and in others 130 per cent.

The formulas recommended in this bulletin are as easy to apply as any of the above-mentioned rules and give results that are much more accurate than any of the old rules.

The formulas recommended for determining the volume of rectangular stacks are as follows:

For low, round-topped stacks $(0.52 \times O) - (0.44 \times W)WL$

For high, round-topped stacks $(0.52 \times O) - (0.46 \times W)WL$

For square, flat-topped stacks $(0.56 \times O) - (0.55 \times W)WL$

The rules for determining volume of round stacks in use at present are not very accurate. On the average the Quartermaster rule gives only 95 per cent, and the Prismoidal rule only 92 per cent, of the actual volume.

The volume of a round stack of a given circumference and over can be determined readily from Table 7. The volume obtained from this table is more accurate than that obtained from either of the above-mentioned rules. Should the circumference or over be greater or less than those given in the table the volume of the stack can be determined by using the following formula $V = (0.04 \times O) - (0.012 \times C)C^2$. This formula will give results that are as accurate as those obtained from Table 7.

If the hay can not be weighed, or the density determined, the cubic feet per ton which may be used with fairly satisfactory results with hay 30 to 90 days in the stack are 485 for alfalfa, 640 for timothy and timothy mixed, and 600 for wild hay, and for hay more than 90 days in the stack, 470 for alfalfa, 625 for timothy and timothy mixed, and 450 for wild hay. These figures, when used with the rules for determining volume given above, will give more accurate results than can be obtained from the figures for cubic feet per ton now in use when employed with present volume rules.

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THE CHEMICAL ERADICATION OF RIBES

By H. R. OFFORD

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CONTENTS

	Page		Page
Introduction	1	Sodium-chlorate sprays—Continued.	
Discussion of early work	3	Relative susceptibility of Ribes	13
Tests of chemicals	5	Observations on killing effect	13
Preliminary tests	5	Factors influencing effective application	18
Repeated application to resistant Ribes	9	Inflammability	18
Application to soil surface about the base of plants	10	Field equipment and methods of spraying chemicals	19
Sodium-chlorate sprays	12	Summary	22
Large-scale tests	12	Literature cited	24

INTRODUCTION

Experiments in the chemical eradication of Ribes [1] have been undertaken during the last several years to find an economical method of killing these plants in situations where simpler methods such as hand pulling and grubbing are not satisfactory.[2] The economic importance of eradication or suppression of these plants is predicated upon the fact that they are the alternate hosts of the fungus *Cronartium ribicola* Fischer, which causes the blister-rust disease of white pines.[3] Eighty or more species of wild Ribes are indigenous to the United States and are found under a wide range of site conditions. Many species occur in association with white pines, where they are noxious weeds because of their rôle in spreading the rust.

The white-pine blister rust was introduced from Europe into North America about 1898. It thrived under conditions on this continent and is now present in the New England States, New York, New Jersey, Pennsylvania, Michigan, Wisconsin, Minnesota, Montana, Idaho, Washington, and Oregon. It is also present in Canada in the Provinces of Nova Scotia, Prince Edward Island, New Brunswick, Quebec, Ontario, and British Columbia.

White pines form a group of forest trees that are among the most valuable commercial timber species in the United States. The forests

[1] The genus name Ribes is used in this bulletin to include both currants and gooseberries.

[2] Laboratory experiments on which were based most of the field experiments herein reported were made possible through the active cooperation of the College of Agriculture of the University of California, specifically the Division of Forestry and the Division of Plant Nutrition. The writer also wishes to acknowledge the suggestions and the interest of P. R. Andrews, Seattle, Wash., R. N. Chipman, Bound Brook, N. J., and E. F. Ross, Olympia, Wash.

[3] White pines indigenous to the United States are: Northern white pine, *Pinus strobus* L.; western white pine, *P. monticola* D. Don; sugar pine, *P. lambertiana* Dougl.; limber pine, *P. flexilis* James; whitebark pine, *P. albicaulis* Engelm.; Mexican white pine, *P. ayacahuite* Ehrenb.; foxtail pine, *P. balfouriana* Murray; and bristlecone pine, *P. aristata* Engelm.

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of northern white pine, western white pine, and sugar pine contain standing timber which is estimated to be worth about $418,000,000. Limber pine, whitebark pine, Mexican white pine, foxtail pine, and bristlecone pine are not used extensively for timber at the present time, but are valued for watershed and scenic purposes. The blister rust is capable of attacking and destroying any tree of these species.

Blister rust spreads chiefly through the medium of wind-blown spores. Through this means it is capable of spreading long distances from diseased pines to the leaves of Ribes, where it undergoes a period of development that produces the spore stage that infects the pines. The distance of spread from Ribes to pines is short because the pine-infecting spores are very delicate and short lived. Therefore, white pines may be protected against blister-rust infection by destroying all Ribes within a comparatively short distance of the trees. This distance varies and is not definitely known for western conditions, but under forest conditions in the East it usually does not exceed 900 feet.

Control of the blister rust has been thoroughly demonstrated in New England and New York, where Ribes have been eradicated during the last 12 years on 7,757,140 acres of land. In these States the cost per acre of eradication has been low because Ribes were comparatively few over much of the area worked and white-pine sites containing very heavy stocking of these plants were not numerous. Under these conditions hand-eradication methods have been used effectively at a cost averaging about 20 cents an acre.

On the other hand, experimental control work in the commercial western white-pine region of the "Inland Empire" (northeastern Washington, northern Idaho, and northwestern Montana) has shown a higher average cost per acre because Ribes are generally more abundant and working conditions more difficult. There the most susceptible species of native Ribes occur in great profusion in the narrow strip of moist deep soil commonly found along the streams in the forested areas. Such locations are referred to as the Ribes "stream type." The two most susceptible species of Ribes in this region, *R. petiolare* Dougl. and *R. inerme* Rydb., are found in large numbers in such locations. In association with them there also occurs the less susceptible *R. lacustre* (Pers.) Poir. The great abundance of Ribes in these moist situations, where the rust finds favorable conditions for development, represents a great source of danger to the adjacent pine stands. Any plan of blister-rust control which is to assure adequate protection to the western white-pine stands of this region must include, as an immediate objective, the eradication of Ribes in these particular locations.

The eradication of Ribes along the forest streams of the "Inland Empire" (fig. 1) is difficult and costly because of the large number of these plants which grow there. Difficulties of eradication, moreover, are not manifested solely in the number of Ribes encountered; certain Ribes occurring in this region layer prolifically, and the task of removing underground stems and broken-off roots is long and arduous; others are rooted either in rock crevices or so intimately with other plants that complete eradication by mechanical means requires undue labor. Under these conditions eradication by the methods of hand pulling and grubbing which have been devised and successfully applied in the Eastern States is very costly. Accordingly,

in 1924 experiments in the chemical eradication of Ribes were started in Idaho. This bulletin reports the progress of certain aspects of this work.

DISCUSSION OF EARLY WORK

The practicability of weed control by chemical methods has been demonstrated clearly by the work of a number of investigators. Brenchley (*4*),[4] Rabaté (*9*), Loyer (*8*), and Schultz (*11*) have done considerable work in Europe, and Aslander (*2*), Bolley (*3*), Long (*7*), Gray (*5*), and Thompson and Robbins (*12*) have made notable contributions from the United States. Their work may be referred to for details as to the herbicides used and for a general bibliography on chemical eradication of weeds.

Experiments in the chemical eradication of Ribes were first begun in the United States at Hobart, N. Y., in 1917, by L. W. Kephart[5] and

FIGURE 1.—Typical alluvial bottom land in the western white pine region of Idaho, showing *Ribes petiolare* along the edge of this slow-flowing stream. Bovill, Idaho, 1926

W. G. Wahlenberg, of the Office of Blister Rust Control. This work was continued during the period 1918–1921 by W. S. Regan, of the Office of Blister Rust Control, who conducted experiments at Hobart, N. Y., and Petersham, Mass. In the course of this work the following substances were tested: Ammonia, arsenic sulphide, arsenic trisulphide, calcium carbide, calcium chloride, calcium cyanide, carbon bisulphide, copper nitrate, copper sulphate, dip oil, formalin, fuel oil, hydrochloric acid, hydrogen cyanide, iron sulphate, kerosene, mercuric chloride, nitric acid, phenol, sodium arsenite, sodium sulphide, spirits of turpentine, sulphuric acid, and four specially prepared chemical

[4] Italic numbers in parentheses refer to Literature Cited, p. 24.

[5] Mr. Kephart was at that time an employee of the Office of Farm Management, Bureau of Plant Industry, but working under the direction of the Office of Blister Rust Control.

substances furnished by a commercial chemical company. The results of these experimental tests eliminated all of the above substances except dip oil, fuel oil, and sodium arsenite.

The following summary of Regan's[6] results with sodium arsenite has been made by the writer after a close study of the unpublished reports on his experiments with this chemical:

Sodium-arsenite solution when sprayed on Ribes plants penetrated the leaves, buds, and stems, and one application killed varying percentages of the plants. Susceptibility of Ribes to this chemical seemed to vary with species, growth habit, and condition of the plants. Ribes with vigorous foliage appeared to be most susceptible. Two or three applications of the chemical usually killed 100 per cent of the bushy forms, while a greater number of applications was necessary to get similar results on skunk currant, *R. glandulosum* Grauer, which has a vinelike growth with many root centers developed along the trailing stems. Although sodium arsenite was fully effective, the chemical was not considered practicable for general use on account of its toxicity to livestock.

The following is a final report on dip oil and fuel oil as given by Regan (10):

Dip oil (25 per cent cresol, 50 cents a gallon) was used straight or diluted with fuel oil. One treatment of dip oil (straight) applied to the top or crown of bushy Ribes kills in the majority of cases. Dilutions with fuel oil of 1 to 5 or 1 to 8 appear most satisfactory for the treatment of the skunk-currant areas, but two or more treatments are required for complete kill.

Dip oil (straight) applied to the tops kills the Ribes foliage in from about one-half hour to a few hours, regardless of exposure to sun or shade. Crown treatment alone usually kills the plants slowly, often requiring several weeks or even months. The efficiency of dip oil appears to be little affected by rain, absence of foliage, or season of application, so long as the treatment is thorough.

Fuel oil (light grade, 36.3° B., 14 cents a gallon) gives best results when applied to the entire top and crown. One treatment will frequently kill bushy species, but often two treatments, rarely three, are required. In areas of skunk currants three or more treatments will usually be required to obtain a complete kill. Dip oil and fuel oil are not poisonous to animals, and do not injure other vegetation if reasonable care is exercised. Where wild currant and gooseberry bushes are large and numerous, or grow in walls or stone piles where hand pulling is difficult, spraying with fuel oil should result in a material saving in cost, although combination with dip oil appears preferable. It does not appear to be economical to treat small plants of the bushy species, which are easily pulled by hand. One-gallon and three-gallon brass compressed-air sprayers are satisfactory for applying the oils.

Regan's work showed that bushy Ribes could be eradicated effectively with mixtures of fuel oil and dip oil. However, the cost of the material and the handling of such a bulky substance in the field limited its usefulness in Ribes eradication, particularly in view of the efficiency of the hand-pulling methods developed for removing Ribes under forest conditions in the Northeastern States. In the course of his chemical work on Ribes, Regan also made a series of tests in the use of chemicals for the destruction of barberry plants.[7]

Experimental work on the chemical eradication of Ribes was first undertaken in the Northwestern States in 1924 by W. F. Huppke.[8]

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[6] REGAN, W. S. PROGRESS OF EXPERIMENTS FOR DESTROYING RIBES WITH CHEMICALS. 1918. (Unpublished manuscript in files, Office of Blister Rust Control.)

[7] These tests were performed in the M. A. Billings farm pasture, Millers Falls, Mass., during October and November, 1919, and August, 1920. Regan (see footnote 6) reports as follows: "Dip oil, fuel oil, salt solution, and sodium arsenite were fully effective on barberry plants. Dip oil gave the highest percentage of kill, but was more difficult to handle and more expensive than salt. Sodium arsenite is least effective and is dangerous to use in areas accessible to livestock. Salt solution (saturated solution, 3 pounds coarse-fine salt to 1 gallon water) gave 100 per cent efficiency when applied to the base, tops, or to the cut-off stumps. This appears to be the cheapest and most easily obtainable of chemicals tested and gave equally good results. Dry salt itself will kill barberry plants when placed about the base of the plants, but it usually requires a longer time and more material than where the solution is used."

[8] Employee of the Bureau of Plant Industry, U. S. Department of Agriculture, working under the direction ofthe Office of Blister Rust Control.

This work consisted of preliminary tests of the toxicity of numerous chemicals on Ribes occurring on small plots in the vicinity of Wallace and Priest River, Idaho. In the course of this work the following chemicals were tested: Acid sludge (50 per cent sulphuric acid), acid sludge oil, calcium chloride, calcium cyanide, calcium hypochlorite, calcium oxide, carbon bisulphide, "Carco," chromic acid, copper carbonate, copper soap in oil, copper sulphate, creosote, Du Pont Dust Disinfectant, Du Pont Weed Killer No. 3, Du Pont Weed Killer No. 4, extra-heavy fuel oil, heavy fuel oil, iron sulphate, lead acetate, light fuel oil, lye sludge oil, magnesium sulphate, manganese sulphate, mercuric chloride, oxalic acid, Paris green, phenol, potassium ferrocyanide, potassium permanganate, sodium acid sulphate, sodium arsenite, sodium chloride, tannic acid, and zinc sulphate. The work was checked over in June, 1925, by Huppke and the writer, and although the results pointed to some interesting possibilities, the evidence was not conclusive, owing to the small number of bushes to which any one chemical had been applied. The following substances had apparently produced some toxic effects on the Ribes plants: Acid sludge (50 per cent sulphuric acid), chromic acid, mercuric chloride, oxalic acid, phenol, potassium cyanide, and potassium permanganate.

After a careful check of the 1924 experiments the writer concluded that either the chemical suitable for the eradication of Ribes had not been found or that an effective chemical had been tested upon too small a scale to give convincing results. It was therefore decided to test again the seven chemicals listed above which had shown the most toxic effect in earlier experiments, and to give preliminary tests to a new list of chemicals which in the writer's opinion had potential merit.

TESTS OF CHEMICALS

PRELIMINARY TESTS

In 1925 three suitable areas for the testing of chemicals on Ribes were selected in Idaho—along Lake Creek near Wallace, along Renfrow Creek near Santa, and along Mary Creek near Clarkia. The area at Wallace represented the particularly marshy land where *Ribes petiolare* and *R. lacustre* abound and was suitable for comparative tests of the chemicals on these species. Scattered clumps of willow and alder provided both shaded and open locations for these Ribes. The plots at Santa were located in a cut-over and burned-over tract adjoining a stream and provided for comparative tests of the chemicals on *R. inerme* and *R. lacustre*. This area was comparatively free of brush and windfalls. The area at Clarkia was located in a typical "stream type" where *R. petiolare*, *R. inerme*, and *R. lacustre* occur in great numbers intermingled with alder and willow brush and provided a good basis for comparative tests of chemical on all three species. The Clarkia area, 2 acres in extent, was reserved for a test of the best ribicide as ascertained by the tests carried on at Wallace and Santa in 1925.

Both the Wallace and Santa areas were laid out in a series of rectangular $\frac{1}{15}$-acre permanent plots. Each plot was subdivided into subplots. The majority of these plots were treated in 1925, but

several plots were reserved at Wallace for use in 1926. Likewise a number of plots were reserved at Santa for use in 1926, 1927, and 1928. In order to keep all data readily available to the field observer, symbols denoting the plot number, station number, chemical used, concentration, and method of application were placed on each subplot stake as a permanent record. The uniformity of the plots at each locality, both as to size and flora, permitted a close comparison between results obtained with the various chemicals.

Before any chemicals were applied on the permanent plots the Ribes were systematically located and data were recorded for the Ribes found on each subplot. A basis for taking data by an ocular estimate of individual bushes was first established by carefully measuring a given number of each Ribes species. Data were taken by ocular estimates in the light of this established measuring stick and included height of bush (average height of erect stems), total linear feet of live stem, and total linear feet of dead stem. Summation of data then gave the total number of bushes, total linear feet of live stem, and total linear feet of dead stem by species for each subplot. The chemical to be tested was then applied over one or more subplots. Ribes data were taken again the year following treatment and compared with the data taken just before the plot was treated.

The results of chemicals tested at Wallace, Santa, and Clarkia, Idaho, between 1925 and 1928 on *Ribes petiolare* and *R. lacustre* are given in Table 1. It was fully realized that some of the chemical substances tested did not meet the necessary requirements of a killing agent for field use, such as cheapness, ready solubility, nontoxicity to men and animals, and noncorrosiveness to equipment. But in order to gain an insight into the action of numerous types of chemicals on Ribes, it was thought desirable to test all the chemical substances listed.

Table 1 arranges in three groups the chemicals tested by spray application to *Ribes petiolare* and *R. lacustre* according to the type of injury produced on these plants. While the final results for these species, which are given in terms of percentages of kill of live stem and bushes, express in a measure the toxic value of each chemical, particular attention should be paid to the grouping of the chemicals. In spite of a careful selection of experimental areas, preliminary observations showed that the age and vigor of the Ribes population varied so greatly that the live stem and bush kill could not be taken alone as the final measure of the effectiveness of the chemicals.

It was recognized that these variations in plant vigor militated against a proper evaluation of the toxic potential of any chemical if measured solely by the reduction of live stems and bushes which followed application of the chemical. Variations in plants might present an indeterminable range of vigor sufficient to account for the death of some bushes or live stem by chemicals very low in killing power, and for failure to kill other plants possessing unusual vigor by chemicals having a high toxic potential. An examination of Table 1 shows that the differences in chemical concentrations and number of bushes treated involve factors that materially influence the figures appearing under the columns headed "Live stem killed" and "Bushes killed." Also because of differences in solubility, corrosiveness, availability, and cost of materials, it was not practicable to test all chemicals in comparable concentrations.

TABLE 1.—*Chemicals tested by single application to leaves and stems of Ribes, grouped according to type of injury produced*

[Except in case of kerosene, which was applied full strength, all chemicals were applied in the form of aqueous solutions]

Chemical used		Chemical concentration [1]	Location (in Idaho) and date of application	Ribes treated					
				R. petiolare			R. lacustre		
Name	Formula			Bushes treated	Live stem killed [2]	Bushes killed [2]	Bushes treated	Live stem killed [2]	Bushes killed [2]
				Number	*Per cent*	*Per cent*	*Number*	*Per cent*	*Per cent*
Group 1: [3]									
Ammonium carbonate.	$(NH_4)_2CO_3.H_2O$	20	Santa, July 21, 1926	0	----	----	119	27	0
Furfural	$C_4H_3O.CHO$	5	Santa, Aug. 9, 1928	10	25	0	14	5	0
Sodium bromide	NaBr	10	Wallace, June 28, 1925	83	4	0	32	13	0
Sodium chloride	NaCl	20	Santa, Aug. 11, 1925	0	----	----	10	27	0
Do	----	10	Santa, Aug. 10, 1925	0	----	----	12	36	0
Sodium fluoride	NaF	4	Santa, July 21, 1925	0	----	----	84	32	0
Sodium tetraborate	$Na_2B_4O_7.10H_2O$	[4] 10	Wallace, June 29, 1925	21	4	0	40	12	0
Via Rasa [5]	----	4	Santa, July 22, 1925	0	----	----	92	16	0
Group 2: [6]									
Ammonium fluoride	NH_4F	4	Santa, July 21, 1926	0	----	----	9	34	11
Ammonium persulphate.	$(NH_4)_2S_2O_8$	25	Santa, July 10, 1927	23	70	4	0	----	----
Do	----	15	do	34	65	3	0	----	----
Copper sulphate	$CuSO_4.5H_2O$	10	Santa, July 18, 1927	12	12	0	9	13	0
Iron sulphate	$FeSO_4.7H_2O$	20	do	7	11	0	21	17	0
Mercuric chloride	$HgCl_2$	2	Wallace, June 29, 1925	125	6	0	15	11	0
Oxalic acid	$H_2C_2O_4.2H_2O$	4	Santa, July 18, 1925	0	----	----	18	56	11
Potassium permanganate.	$KMnO_4$	15	Santa, July 10, 1928	15	70	13	0	----	----
Sodium bromide plus sodium hydroxide.	NaBr+NaOH	8 + 4	Santa, July 22, 1925	0	----	----	20	32	0
Sodium hydroxide	NaOH	4	Santa, July 18, 1925	0	----	----	199	57	6
Sodium hydroxide plus sodium fluoride.	NaOH+NaF	2 + 4	Santa, July 17, 1925	0	----	----	199	29	0
Sodium hypochlorite (commercial product).	NaOCl	[7]	Santa, June 26, 1928	0	----	----	48	46	4
Sulphuric acid	H_2SO_4	4	Santa, July 10, 1928	0	----	----	19	51	5
Group 3: [8]									
Ammonium chloride	NH_4Cl	30	Santa, Aug. 9, 1927	0	----	----	5	60	40
Do	----	25	Santa, July 20, 1926	0	----	----	143	79	19
Do	----	20	Santa, Aug. 28, 1925	0	----	----	15	98	7
Kerosene	----	[9]	Santa, Aug. 19, 1925	0	----	----	13	75	61
Potassium bromate	$KBrO_3$	5	Santa, July 22, 1925	0	----	----	26	42	19
Potassium chlorate	$KClO_3$	[4]	Wallace, June 8, 1926	113	97	68	67	67	36
Potassium chlorate plus sodium hydroxide.	$KClO_3$+NaOH	[10]	do	50	75	26	0	----	----
Sodium chlorate	$NaClO_3$	50	Wallace, June 28, 1925	41	100	97	62	100	72
Do	----	25	do	106	100	99	77	98	58
Do	----	25	Santa, July 15, 1925	0	----	----	355	91	43
Do	----	25	Clarkia, Aug. 1–31, 1926.	2,710	100	99	4,700	65	24
Do	----	15	Santa, Aug. 29, 1925	70	100	100	424	77	14
Do	----	10	do	23	99	96	25	71	8

[1] Concentration expressed as percentage by weight.

[2] In these columns the closer whole number was used for fractions of 1 per cent. An even 0.5 per cent appears as the lower digit.

[3] No appreciable injury to Ribes leaves and stems; vigor of average plant remains unchanged.

[4] Supersaturated.

[5] Trade name for a mixture of ferric salts.

[6] Rapid initial injury to Ribes leaves and stems; vigor of plant temporarily affected followed by rapid reestablishment of bush.

[7] Half strength.

[8] Slow and complete killing of Ribes leaves and succulent stems, followed by slow and partial to complete death of older stem; partial to complete killing of bushes; vigor of plants permanently affected.

[9] Full strength.

[10] Potassium chlorate 5 to 6 (supersaturated), sodium hydroxide 2.

It soon became apparent, therefore, that results must be judged by two criteria: (1) The end result of whether or not death of the plant ensued, and (2) the type of injury produced, as indicated by

definite symptoms shown by the treated parts of the plant. Accordingly, the complete record of each experiment included careful observations of the injury as it developed on the treated plants, as well as final data on percentage kill of live stem and of bushes, obtained the year following treatment.

The experiments reported in Table 1 have been divided into three groups, so that uniformity of results in regard to the general lowering of plant vitality is given proper consideration. If the percentages of live stem and bushes killed are then considered in the light of the characteristic injury described for the particular group in which they appear, a more accurate comparison can be made of the killing potentialities[9] of the chemicals tested. The types of injury to Ribes caused by the three groups of chemicals are as follows:

Group 1. No appreciable injury to Ribes leaves and stems. Vigor of average plant remains unchanged. *R. petiolare*, live stem killed, 4 to 25 per cent, bushes killed, none. *R. lacustre*, live stem killed, 5 to 36 per cent; bushes killed, none.

This group represents those chemicals which had little or no effect on the Ribes treated. In some cases a few leaves and some succulent stem growth were killed, but for the most part killing action was either not apparent or manifested only by a slight browning of the leaf margins where concentration of the chemical had occurred. Toxic action is primarily attributed to osmotic effects on the part of the applied sprays. Reference to Table 1, Group 1, shows that the injury produced by these chemicals was limited to the killing of comparatively low percentages of the live stem. It should be kept in mind that the figures for live-stem kill in this group for both *R. petiolare* and *R. lacustre* signify current-season stem.

Group 2. Rapid initial injury to Ribes leaves and stems. Vigor of plant temporarily affected, followed by rapid reestablishment of bush. *R. petiolare*, live stem killed, 6 to 70 per cent; bushes killed, 0 to 13 per cent. *R. lacustre*, live stem killed, 11 to 57 per cent; bushes killed, 0 to 11 per cent.

This group represents those chemicals which produced considerable initial injury, from which most of the plants recovered. The extent of injury varied greatly, as follows: Rapid and in many cases complete kill of leaves, followed by partial to complete kill of current-season stem, with partial to complete killing of old stem and an occasional bush completely killed. Partial killing was followed by rapid releafing with new leaves, green and quite normal in appearance. The highly caustic or rapidly poisonous chemicals in this group are not the substances most toxic to Ribes. The Ribes put out new leaves in almost direct ratio to the speed of defoliation. In many cases plants seemed to be stimulated to renewed growth by such treatment. Toxic action of this group of chemicals appears to consist of the caustic effect of acids and alkalies and the precipitating or coagulating power of heavy metal ions.

In general the percentages of live-stem and bush killing for the chemicals listed in Group 2 show a definite increase over those in Group 1, although it is apparent that the chemicals in Group 2 are not sufficiently toxic to make them practical for field use. In this group some 1 and 2 year old stem was killed as well as the current season's growth. If judged solely on the criterion of percentage kill of bushes,

[9] Data have been recorded only for Ribes, but observations of associated brush made by the writer suggest that the general effects described for the three groups hold good for other perennials. By arranging the experiments as shown in Table 1, it is hoped that the information therein is made more useful to those interested in the eradication of noxious weeds other than Ribes.

some of these chemicals might be called border-line compounds between Groups 2 and 3. However, in view of the quick toxic action and the rapid, vigorous releafing that followed the initial injury caused by their application, they most certainly all belong in Group 2.

Group 3. Slow and complete killing of Ribes leaves and succulent stems, followed by slow and partial to complete death of older stem. Partial to complete killing of bushes. Vigor of plants permanently affected. *R. petiolare*, live stem killed, 75 to 100 per cent; bushes killed, 26 to 100 per cent. *R. lacustre*, live stem killed, 42 to 100 per cent; bushes killed, 7 to 72 per cent.

This group represents those chemicals which tend to produce permanent injury. In contrast with the rapid and temporary injury produced by the chemicals in Group 2 was the slow sickening and dying of the plants treated with the chemicals in this group, following the slow and complete killing of the leaves. The symptoms are fairly uniform and consistent on all plants of the same species. Individual plants that do not succumb are so reduced in vitality that they recover very slowly. While the question of absorption and translocation of a poisonous chemical by a perennial is beyond the scope of this bulletin, it is certain that those chemicals which act very slowly on the leaves and succulent stems of Ribes are much more effective than those which act rapidly. Slow-acting poisons, such as sodium chlorate, appear to act in rather a fundamental fashion when sprayed on the aerial portions of plants, and it is the writer's opinion that this is characteristic of the compounds that will prove most useful in future methods of chemical suppression of weeds. Later in this bulletin some tentative suggestions are made concerning the mechanism of the toxic action of sodium chlorate.

Analysis of similar field data for *Ribes inerme* showed this species to be generally more resistant to chemicals than *R. petiolare* and *R. lacustre*; however, the three types of injury described for these species also held true for *R. inerme*. The chemicals tested by spray application[10] to *R. inerme* are arranged below in three groups on the same basis as those described for *R. petiolare* and *R. lacustre*.

Group 1. Ammonium carbonate, ammonium bromide, ammonium nitrate, calcium chloride, calcium hypochlorite, paradichlorobenzene, calcium paratoluenesulphonamide, potassium fluoride, potassium sulphate, sodium bromide, sodium chloride, sodium fluoride, sodium sulphate, sodium paratoluenesulphonamide, sodium sulphite, sodium tetraborate, Via Rasa.

Group 2. Acetic acid, aluminum sulphate, ammonium fluoride, ammonium persulphate, chromic acid, copper sulphate, hydrochloric acid, oxalic acid, perchloric acid, phenol, potassium cyanide, potassium permanganate, sodium bromide plus sodium hydroxide, sodium dichromate, sodium hydroxide, sodium hydroxide plus sodium fluoride, sodium hypochlorite, sulphuric acid, zinc chloride.

Group 3. Ammonium chloride, kerosene, potassium bromate, potassium chlorate, sodium chlorate.

REPEATED APPLICATION TO RESISTANT RIBES

The poor results obtained with sodium chlorate on *Ribes lacustre* and *R. inerme* by a single application of an aqueous spray led to some experiments dealing with the effect of two and three applications of chemicals. For these experiments sodium chlorate and ammonium chloride were selected from Group 3 on account of their relatively higher toxicity to the resistant species and were compared with sodium hydroxide, which was considered as representing Group 2. Until some chemical from Group 2 showed real promise it was felt that

[10] Kerosene was applied full strength as a spray, calcium hypochlorite was dusted on, and the other chemicals were applied in the form of aqueous solutions.

chemicals of the still lower toxicity represented by those of the Group 1 type could be ruled out as possessing no possibilities even for repeated application, and therefore no chemical from Group 1 was included in this test. In order to account for the injury that might be expected to occur by reason of repeated defoliation, the results of chemical defoliation were compared with defoliation accomplished by hand picking the leaves.

The experiments reported in Table 2 show the results of successive spray applications of sodium hydroxide, sodium chlorate, and ammonium chloride to the leaves and stems of *Ribes lacustre* and *R. inerme*, as well as the results of repeated defoliation by hand picking the leaves. These data show that three applications of a cheap defoliator such as sodium hydroxide 4 per cent are not appreciably more toxic to Ribes than the same number of defoliations accomplished by hand. Second and third applications of ammonium chloride 12½ per cent are more toxic than the same number of applications of sodium hydroxide 4 per cent, even though the concentration of ammonium chloride in this experiment was considerably lower than the one of optimum toxicity shown in Table 1. The increased effectiveness of sodium chlorate over the superficially toxic chemicals like sodium hydroxide is clearly shown and further confirms the earlier observation concerning the peculiarly fundamental action of this chemical. Three applications of a 25 per cent solution of sodium chlorate to *R. lacustre* and *R. inerme* gave from 98 to 100 per cent kill of the treated plants.

TABLE 2.—*Chemicals tested by two or more spray applications to leaves and stems of Ribes at Santa, Idaho*

Chemical used	Chemical concentration [1]	Bushes treated		Date of application	Live stem killed [2]		Bushes killed [2]	
		R. lacustre	R. inerme		R. lacustre	R. inerme	R. lacustre	R. inerme
		Number	*Number*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sodium hydroxide	4	64	248	July 5, 1925	38	30	6	3
				July 8, 1926	41	39	8	4
				July 2, 1927	75	56	11	12
Sodium chlorate	25	175	72	July 23, 1925	83	63	40	15
				July 14, 1926	93	91	90	60
				July 12, 1927	100	98	100	98
Do	15	106	146	July 24, 1925	69	38	14	3
				July 18, 1926	89	58	18	5
Do	10	25	145	Aug. 28, 1925	63	29	8	5
				July 15, 1926	93	47	12	8
Ammonium chloride	12½	23	87	July 17, 1925	31	23	0	2
				July 12, 1926	62	53	13	7
				July 3, 1927	90	74	20	14
Leaves stripped from bushes by hand	-------	13	165	Aug. 7, 1925	12	2	0	0
				July 14, 1926	24	35	0	0
				July 2, 1927	98	44	15	3

[1] Concentration expressed as percentage by weight.
[2] The closer whole number was used for fractions of 1 per cent. An even 0.5 per cent appears as the lower digit.

APPLICATION TO SOIL SURFACE ABOUT THE BASE OF PLANTS

The experiments reported in Table 3 were performed to obtain preliminary data concerning the practicability of killing Ribes by applying chemicals to the soil surface about the base of the plants. Regan's work had shown that the practical use of this method of treatment should be largely confined to bushy forms of Ribes that have simple root systems and that under certain conditions it was more expensive than hand pulling. The Ribes found in the "stream-type" locations of the "Inland Empire" have complex root systems as the result of profuse layering, and it was obvious that this method would be too

costly on such bushes. However, areas are found in this region where *R. lacustre* and *R. inerme* occur abundantly as single bushes or are rooted in rock crevices. Such conditions render hand pulling or grubbing difficult and costly.

Data in Table 3 show the relative merits of the chemicals tested by application to the undisturbed soil surface about the base of *Ribes lacustre* and *R. inerme*. In the only two tests that included both species, *R. lacustre* appeared more susceptible to the chemicals by this method of treatment than *R. inerme*. One quart per bush of a 25 per cent aqueous solution of sodium chlorate killed 100 per cent of the *R. lacustre* bushes so treated. Eight additional chemicals were applied to *R. inerme*. Equal parts by volume of acid sludge and water, one-half pint per bush; sodium chlorate, 25 per cent aqueous solution, 1 quart per bush; ammonium chloride, one-half to 1 pound per bush; kerosene plus an equal part of acid sludge, one-half to 1 pint per bush; and sodium hydroxide 4 per cent plus sodium fluoride 5 per cent in aqueous solution, 1 quart per bush, in the order named, killed from 65 to 100 per cent of the bushes of *R. inerme* treated. All factors considered, of the chemicals listed in Table 3, sodium chlorate or the sodium hydroxide-sodium fluoride mixture are probably best adapted to the chemical eradication of Ribes by soil treatments such as used in these experiments.

TABLE 3.—*Results obtained by applying chemicals to the soil surface about the base of Ribes plants, Santa, Idaho*

Chemicals used	Quantity applied per bush	Date of experiment	Ribes treated			
			R. lacustre		R. inerme	
			Bushes killed [1]	Bushes treated	Bushes killed [1]	Bushes treated
			Per cent	*Number*	*Per cent*	*Number*
Ammonium chloride (dry)	½ to 1 pound	Aug. 15, 1925			88	26
Ammonium chloride [2] 20 per cent+; sodium hydroxide, 2 per cent.	1 pint	Aug. 4, 1925			11	8
Acid sludge,[2] 1 part; water, 1 part	½ pint	Aug. 27, 1925			65	17
Calcium chloride (dry)	½ to 1 pound	Aug. 4, 1925			15	60
Kerosene (full strength)	1 pint	Aug. 19, 1925			46	13
Kerosene, 1 part by volume; acid sludge, 1 part by volume.	½ to 1 pint	do			92	12
Sodium chlorate,[2] 25 per cent	1 quart	July 23, 1925	100	18	75	16
Sodium chloride (dry)	1 to 5 pounds	July 15, 1925	50	16	12	8
Sodium hydroxide,[2] 4 per cent; sodium fluoride, 5 per cent.	1 quart	do			100	11
Sodium tetraborate (dry)	½ to 1 pound	July 21, 1925			11	27

[1] In columns 4 and 6 the closer digit was used for fractions of 1 per cent. An even 0.5 per cent appears as the lower digit.
[2] Aqueous solution.
[3] A waste product of the oil-refining industry containing a high percentage of H_2SO_4.

It was found that in applying chemicals to the soil about the base of Ribes bushes, either in solution or in solid form, best results were obtained when the chemical was applied so that leaching or flow of solution took place across the root system of the plant. The anomalies of root distribution doubtless accounted for some of the inconsistencies obtained by the writer in these experiments. While the scope of these experiments is limited, the good results obtained in the case of several of the chemicals suggest that this method of chemical eradication may be of value on plants with simple root systems where cheaper methods are not effective. Additional experiments of this nature are now under way in the sugar-pine region where a scarcity

of water renders spraying impracticable. Under these conditions a toxic hygroscopic dust applied to the aerial parts or about the base of Ribes may prove to be an effective and economical ribicide.

SODIUM-CHLORATE SPRAYS

LARGE-SCALE TESTS

It is apparent from the results obtained by the tests of chemical sprays on Ribes in 1925 and 1926 that the sodium and potassium salts of chloric and bromic acids were the only substances that gave real promise of desired results. The field tests showed these chemicals to be consistent in their effect and in the case of *R. petiolare* to give sufficient kill to merit further and more intensive experimentation. After careful consideration of these substances it was decided to test the killing effect of sodium chlorate on Ribes on a much larger scale in 1927. Potassium chlorate was eliminated because of its relative insolubility. It was also decided to discontinue experiments with the bromates because of their relatively high cost and the limited possibility of securing them in large quantities. The uniformity of results secured with these oxyhalogen compounds made it possible to eliminate all but the cheapest and most readily usable. Plans were therefore made to test the toxic effect of aqueous solutions of sodium chlorate on Ribes on a sufficiently large scale to eliminate the effect of local variations in these plants.

An area was selected on the East Fork of Potlatch Creek, several miles east of Bovill, Idaho. It consisted of the customary narrow belt of stream land, traversing in this particular case a large area of logged-off land. It contained the three Ribes species *R. petiolare*, *R. lacustre*, and *R. inerme*.

During the course of the 1927 field season the Ribes on four plots totaling 27.59 acres of "stream type" were sprayed with different solutions of sodium chlorate. Four spray solutions, representing two concentrations of the chlorate and two spreaders, were used, one to each plot, as follows: Solution No. 1, $NaClO_3$, 25 per cent; solution No. 2, $NaClO_3$, 25 per cent plus fish-oil soap; solution No. 3, $NaClO_3$, 25 per cent plus glue; solution No. 4, $NaClO_3$, 20 per cent. Results of these tests are shown in Table 4.

TABLE 4.—*Results of application of sodium-chlorate spray to the leaves and stems of Ribes, 1927, Bovill, Idaho*

Spray solution	Date of application	Area sprayed	R. petiolare				R. lacustre				R. inerme			
			Growth treated		Growth killed[1]		Growth treated		Growth killed[1]		Growth treated		Growth killed[1]	
			Live stem	Bushes	Live stem	Bushes	Live stem	Bushes	Live stem	Bushes	Live stem	Bushes	Live stem	Bushes
		Acres	*Feet*	*Number*	*Per cent*	*Per cent*	*Feet*	*Number*	*Per cent*	*Per cent*	*Feet*	*Number*	*Per cent*	*Per cent*
No. 1	July 1–15	9.16	102,150	2,043	100	[2]99+	21,150	846	99	59	48,600	1,944	93	32
No. 2	July 10–30	6.11	68,100	1,362	100	99+	15,100	604	88	14	32,400	1,296	62	[3]
No. 3	July 15–30	5.44	56,250	1,125	100	99+	10,750	403	93	42	27,000	1,080	72	[3]
No. 4	Aug. 1–7	6.88	26,000	520	100	99+	5,100	204	84	19	16,000	640	73	6

[1] The closer whole number was used for fractions of 1 per cent. An even 0.5 per cent appears as the lower digit.

[2] *Ribes petiolare* was completely susceptible. Occasionally a small plant escaped treatment in the application.

[3] Complete data were not taken on the number of bushes killed.

Data given in Table 4 show the high kill obtained by the use of sodium-chlorate spray on *Ribes petiolare* bushes in contrast with the poorer results obtained on *R. lacustre* and *R. inerme*. The chemical was more evenly distributed over the stems and leaves and remained there much better in cases where a sticker was used. It is believed that the variation in the effectiveness of the spray on *R. lacustre* and *R. inerme*, the less susceptible species, was due to other causes than the possible reduction of toxicity by the sticker. The results of the experiments for *R. petiolare* and *R. lacustre* agree in general with those shown in Table 1. Subsequent chemical eradication work with sodium chlorate undertaken on a large scale at Bovill, Idaho, and at Haugan, Mont., in 1928 showed practically the same general differences in the susceptibility of *R. petiolare*, *R. lacustre*, and *R. inerme* to this chemical, as indicated in Table 4.

RELATIVE SUSCEPTIBILITY OF RIBES

Reference to Tables 1 and 4 show that practically 100 per cent of *Ribes petiolare* is completely killed by a single application of an aqueous solution of sodium chlorate, 10 to 50 per cent by weight, sprayed on the leaves and stems. The killing shown by Figures 2 and 3 is representative of the areas treated with sodium chlorate from which the data in Table 4 were obtained. A number of complete kills of *R. inerme* and *R. lacustre* were obtained over any area so treated, but the average effectiveness of the chemical was much lower on these species. Considerable sprouting takes place from the crown of both *R. lacustre* and *R. inerme* (fig. 4), whereas the plants are completely killed in the case of *R. petiolare*, provided the application is thorough. Data in Tables 1 and 4 show that these Ribes species are definitely arranged in an order of decreasing susceptibility to sodium chlorate as follows: *R. petiolare*, *R. lacustre*, *R. inerme*.

Recent experimental work has indicated that the concentration of sodium chlorate necessary for complete eradication of *R. petiolare* can be reduced to about 10 per cent by making the spray slightly acid (pH 5.0 to 6.5).

OBSERVATIONS ON KILLING EFFECT

Sodium chlorate has been used in Europe as a weed eradicator for a number of years. Loyer (*8*) says that work should be done in April, May, or early June. Seven to eight kilos per hectare of $NaClO_3$ are used. A mixture of $NaClO_3$ and $NaNO_3$ can be used. Rabaté (*9*) says that 250 kilos of $NaClO_3$ per hectare will destroy all vegetation. He used $NH_4\ ClO_3$ and found it to be quite effective. It had a slow action on the leaves which was not apparent for some days.

The first published report on the use of sodium chlorate as a herbicide in the United States was made by Åslander (*1*), who sprayed *Cirsium arvense* Scop. with $NaClO_3$ 10 per cent and $KClO_3$ 6.5 per cent. He observed that the epidermis and the cortex were first affected and that dilute solutions of $NaClO_3$ were selective in their action. Latshaw and Zahnley (*6*) found that a 12½ per cent solution of $NaClO_3$ was very effective when sprayed on bindweed, *Convolvulus arvensis* L. The first spray was most active if applied about the time the plants were in full bloom. They noticed, moreover, a considerable diminution of the starch content in the roots of treated plants.

When sprayed on Ribes in aqueous solution of sufficient strength to kill the live stem of the plant, the first obvious effect of sodium chlorate is a slight curling of the leaves. In hot weather this may occur

a few hours after application of the chemical. Two days after treatment the leaves begin to turn brown. The succulent stems of the current year's growth show a marked darkening in color of the epidermis about the time that browning of the leaves occurs. Brown spots appear in the cambium four or five days after treatment. All succulent stem growth is usually dead at the end of the first week. The older stems show a similar effect from the action of the chemical after 12 to 14 days. Shortly after the effect of the chemical has become noticeable in the cortex of the woody stems, progress of the killing action is manifested by the appearance of a dark brown coloration in the medullary rays and pith. In the last stages of injury the bark sloughs quite easily from the woody stem. The entire plant is killed to the ground in this manner during the course of the season. In the case of *R. petiolare* the roots are, for the most part, killed during the two or three months following application. Life has been

FIGURE 2.—Dense understory of *Ribes petiolare* completely killed by one application of $NaClO_3$, 25 per cent. Sprayed on leaves and stems, August, 1926. Photographed July, 1927, Clarkia, Idaho

observed in some old *R. petiolare* crowns the ensuing spring, but no sprouting takes place, and one year from the date of treatment *R. petiolare* bushes are completely dead. The effect of the chemical on the stem as described above is slower in the case of *R. lacustre* and *R. inerme*, and in a large percentage of cases these species reestablish themselves by sprouting from crowns.

The typical action of sodium chlorate on Ribes, as described above, may be varied to a greater or less extent by certain of the individual plant's environmental factors. The rate of action of the chlorate varies considerably with the degree of exposure of the plant, although the final results seem to be the same in all cases. Ribes exposed to direct sunlight often show a curling of the leaves three or four hours after application of the spray. Shade forms, on the other hand, may only show this characteristic slight curling over periods of four to six days after application, and the subsequent manifestations of injury are similarly delayed.

Observations made on sprayed areas showed that the action of the chlorate is faster on Ribes in moist habitats than on plants occurring in drier locations.[11] It is also evident from the results of these field

FIGURE 3.—*Ribes petiolare* with an overstory of alder and willow. Ribes are completely killed, as well as the greater portion of the brush canopy. Note the 40 to 60 year stand of white pine in the background, which is protected from blister rust by the destruction of the Ribes. Leaves and stems sprayed with sodium chlorate, August, 1926. Photographed July, 1927, Clarkia, Idaho

[11] The action of sodium chlorate on brush plants commonly associated with Ribes has been carefully observed during the course of experimental work. *Alnus* sp., *Salix* sp., and *Cornus* sp. apparently respond to sodium-chlorate treatment in the same manner as *R. petiolare*. These plants, essentially moisture loving, are often completely killed by a single application of sodium-chlorate spray to the aerial parts, inadvertently applied while spraying Ribes.

tests that the manner of application may vary the effectiveness of the spray. The toxic effect seems to be greater when the spray is applied to the lower leaf surface than to the upper. The significance of these facts can be determined only by detailed studies on the structure and physiology of the species concerned. Such studies are now under way.

Sodium chlorate is most effective when applied early in the growing season just after the Ribes have fully leafed out. *R. inerme* and *R. lacustre*, the most resistant species, exhibit a stronger seasonal variation than *R. petiolare*. A small amount of releafing has been observed on *R. petiolare* when the chlorate is applied late in the growing season, but the bushes do not live over the winter. *R. inerme* and *R. lacustre*, on the other hand, show less injury when the chemical is applied late in the year. Occasionally *R. inerme* and *R. lacustre* will sucker from the crown the second year after application of the

FIGURE 4.—*Ribes inerme* showing typical development of sprouts from the crown one year after spraying the leaves and stems with $NaClO_3$. The overstory is willow. Clarkia, Idaho, 1927

chlorate. In the case of *R. petiolare*, however, any tendency of the plant to reestablish itself is manifested the year following treatment.

The ideal time for application of sodium chlorate to Ribes seems to be early in the growing season during dull cloudy weather.[12] If the sun is too hot immediately after application, a certain amount of the chemical will dry on the leaf and scale off, particularly if a high wind prevails. A period of warm bright weather for a few days after

[12] It is interesting to note the observations that have been made by other investigators concerning the most favorable time for applying herbicide. Bolley (*3*) recommended humid weather for the application of weed sprays and found the condition favoring rapid growth to be the most satisfactory. Gray (*5*) states that sodium arsenite acts most vigorously on wild morning-glory if the plant is "approaching or wholly within the dormant state." Aslander (*2, p. 1088*) in his report on sulphuric acid as a weed killer states "* * * The mustard plants were killed under all conditions of humidity, but best results were obtained in dry air." When he used iron sulphate, however, the reverse was true, and in the same paper he states: "A solution of iron sulphate was found to be most destructive in an atmosphere containing about 100 per cent relative humidity." It seems evident that the type of inorganic salt which acts slowly is most favorably applied when the air is damp and that a film of moisture on the leaf is essential before maximum toxicity can be obtained.

the spray is applied and the presence of dew at night with comparatively high humidity during the day are favorable to the toxic action of sodium chlorate. Rain two hours after spraying does not materially reduce the toxic action of this chemical.

In the light of a widespread interest in the use of sodium chlorate as a herbicide it may be of some interest to set down a few suggestions concerning the possible mechanism of its toxic action, which have resulted from several years' field and laboratory experience with chemical eradication of Ribes. The high oxidizing potential of sodium chlorate and the readiness with which this compound gives up its oxygen when intimately associated with organic matter is a well-known chemical fact. The chlorate ion possesses another unusual property in that it contains chlorine in the pentavalent form. In the process of the decomposition of aqueous sodium chlorate in a slightly acid solution, both nascent oxygen and highly reactive chlorine might be formed, both of which would act as intense poisons to plasma proteins. The writer has recently shown, in the course of the laboratory experiments mentioned, that exposure to ultra-violet light for a few minutes brings about a decomposition of sodium chlorate as manifested by the appearance of free chlorine in the solution. Obviously the light intensity within the intercellular spaces that finally reaches the chloroplasts in the case of sprayed plants does not approach the intensity employed in the above-mentioned ultra-violet light experiment, but it is quite conceivable that a decomposition of chlorate, catalyzed by direct sunlight, would take place slowly over a long period of time under field conditions. Moreover, the slowness of this reaction is quite consistent with the slow sickening results noted following application of sodium chlorate to a plant.

Experiments carried out at Berkeley, Calif., have also shown quite conclusively that the chlorate ion is present as such in the roots of plants following the application of the aqueous spray to the aerial parts. Apparently the sodium-chlorate molecule, or the chlorate ion, is translocated within the plant during some of the processes of metabolism and by virtue of this fact exerts more than a local, superficial action. It is also certain that a rapid depletion of the stored carbohydrates occurs shortly after treatment with sodium-chlorate spray. Whether this disappearance of carbohydrate is the result of a specific reaction between sodium chlorate and the starches or sugars or merely the usual response that a plant makes to injury is unknown at the present time. So far it has not been possible to demonstrate that sodium chlorate will oxidize starches or sugars in vitro, though it is possible that direct oxidation may occur within the plant in the presence of some starch-hydrolyzing enzyme. The possibility that sodium chlorate can stimulate plant respiration to an unusual degree has also been considered, though no conclusive evidence has been obtained as yet to show that this takes place to any significant extent.

Briefly, the peculiarly fundamental toxic action exerted by sodium chlorate might be explained by (1) the fact that it is rather passive in the early stages, thus allowing movement of the poison within the plant, and (2) by the fact that over an extended period a slow decomposition with a corresponding change in the oxidizing potential of the chemical occurs in the superficial layers of the plant catalyzed by sunlight and within the plant tissue by virtue of reducing substances such as tannins or reducing sugars under the stimulus of life processes.

FACTORS INFLUENCING EFFECTIVE APPLICATION

Field experiments showed conclusively that whenever an aqueous solution of sodium chlorate 10 to 50 per cent was thoroughly sprayed on the leaves and stems of *Ribes petiolare*, a complete kill was obtained. The striking difference in susceptibility between *R. petiolare* on one hand and *R. inerme* and *R. lacustre* on the other suggested that, aside from physiological differences between species, the chemical was not being effectively applied in all cases. Several factors militate against the successful application of a spray to *R. inerme*. The screening effect of associated brush is greatest for *R. inerme*. This species, moreover, has a habit of sending out long branches which may lie prostrate on the ground or climb about the overstory of brush. Frequently parts of this plant are missed during the course of field spraying. Another factor that undoubtedly contributes to the difference in susceptibility of the aforementioned Ribes is the difference between species in area of leaf surface per foot of live stem. *R. petiolare* has a much larger area of leaf surface per foot of live stem than *R. inerme* and *R. lacustre*. Finally, *R. petiolare* has a thinner bark, is more succulent, and has a smaller amount of protective tissue than the other two species.

The tendency of the spray to run off or form large drops on the leaves of some plants has been largely overcome by the use of stickers and spreaders. Calcium caseinate, flour, fish-oil soap, glue, glycerin, linseed oil, and soap have been added in different amounts to the chlorate sprays to act as stickers and spreaders. Of these compounds, fish-oil soap or glue, 0.01 to 0.05 per cent by weight of the dry chemicals used, were found to be the most satisfactory. If soap is used, about one-third pound is shaved into a small volume of water, the temperature of which is slowly raised until the soap has completely dissolved. Water is then added to make 1 gallon of stock solution. About one-fourth to one-half pint of this stock solution is added to each 10 gallons of water in the mixing tank before adding the sodium chlorate. Careful addition of the sodium chlorate is necessary in order that the soap remain in solution. If the fish-oil soap is poured into a concentrated chlorate solution, the soap is immediately salted out and rises to the top in the form of an insoluble scum. A stock solution of glue is prepared by dissolving one-third pound of the amber-colored flake glue in 1 gallon of water. This is more readily done by soaking the glue in a small volume of cold water overnight. The following day the glue is made up to 1 gallon by adding slowly small quantities of boiling water. About one-fourth to one-half pint of stock glue solution is used for each 10 gallons of spray solution. Care is taken to avoid an excess of glue, particularly in the case of water containing appreciable suspended organic matter.

INFLAMMABILITY

An intimate mixture of sodium chlorate and any form of dry organic material in a state of fine division is very combustible. It should be noted that the results of experiments reported in this bulletin deal with a considerable range in concentration of sodium chlorate. However, solutions of this chemical stronger than 10 per cent by weight (0.89 pound per gallon of water) are not recommended for general field use, owing to the risks involved in handling it by those not familiar with its chemical properties.

Clothing is extremely inflammable if it becomes saturated with sodium chlorate and is allowed to dry out completely. Persons

engaged in spraying chlorates should keep their clothing slightly damp at all times, particularly during hot weather when the humidity is low, and clothing should be carefully washed at the conclusion of the day's work.

An asphaltum waterproof paint has been applied to the lower portions of the trousers to prevent the chlorate from actually soaking into the fiber. This measure provides a margin of safety. Methods of fireproofing cloth by precipitating insoluble salts of heavy metals in the fiber are being investigated. It is proposed to combine a fireproofing and waterproofing process for treatment of clothing in order to reduce the danger.

Special care should be exercised in the handling of sodium chlorate on account of the unstable nature of the compound. Kegs of the chemical should not be dropped or rolled about needlessly and should be stored in a cool place and piled so as to allow a circulation of air.

FIELD EQUIPMENT AND METHODS OF SPRAYING CHEMICALS

The problem of spraying chemicals under field conditions falls naturally into two parts: (1) The selection of spraying equipment suitable for field use, and (2) the methods of handling men and equipment over areas to be sprayed. A careful survey of all types of spraying equipment manufactured in this country was made by the writer in 1925. This survey comprised actual inspection of equipment and an intensive study of catalogues where it was found inconvenient to visit the shop of the manufacturer.

The available power spraying units were all made for orchard or park spraying and were far too heavy and cumbersome for use under forest conditions. The portable forest-fire pump was more nearly suited than anything else to the needs of chemical eradication of Ribes along forest streams. This unit as it was originally built delivered large volumes of liquid and consequently was not suitable for spraying operations where conservation of the spray was a vital factor. However, it is possible to reduce the volume discharge of this unit and at the same time build up the pressure. Investigative work has been conducted on the construction of a small portable power sprayer specifically designed for chemical eradication work.

Experimental power units were completed in the spring of 1927 and were put through exacting field tests that summer. Experience with these units showed that it would be possible to develop economic methods based on the use of power spraying equipment for the eradication of Ribes where they occur in great profusion. Final specifications have not been reached, but it is certain that a unit weighing less than 80 pounds can do the work satisfactorily.

The essential features of the portable power sprayers that have been tested in the field consist of a small gas engine connected to a rotary pump capable of developing a working pressure of 75 to 150 pounds; a by-pass valve adjustable to any desired working pressure, which returns part or all of the spray solution to the mixing tank and takes care of the intermittent demands of the spray nozzles; and a specially designed frame made of a lightweight metal (aluminum alloy) which enables the unit to be readily transported on a man's back. Gasoline tank and battery are concealed in the base of the frame. The relative merits of air-cooled and water-cooled motors, of battery and magneto ignition, of single-stage and double-stage rotary pumps, and the question of the most convenient weight and the most efficient horse-

power of the unit compatible with practicable field management are still subjects of experimentation.

Apparently, half-inch main-line hose and quarter-inch laterals connected to the main line offer the best opportunity of efficient crew management. A mechanic who is in charge of the pumper at the "filling station" can keep the supply of spray solution mixed and can start and stop the power unit according to signals given by the foreman in charge of spraying operations. Figure 5 shows a typical set-up at a "filling station."

Two types of hand sprayers have been used in experimental plot work and in the development of field methods for large-scale chemical work during the years 1925 to 1927, inclusive, namely, a 3-gallon compressed-air sprayer and a 4-gallon knapsack sprayer with pump attachment. The compressed-air type has been found most useful for

FIGURE 5.—A typical set-up of the power pumper at a so-called "filling station." The chemical is mixed in large wash boilers

plot work where small quantities of experimental sprays are applied in areas free from brush and windfall. This sprayer is the common type of compressed-air unit used for garden and orchard work and needs no further description. After preliminary field tests undertaken in 1925, 1926, and 1927, the knapsack type was recognized as being much more suitable than the compressed-air sprayer for general field work, and since 1927 it has been the subject of much experimentation designed to make it more efficient for this kind of work.

Since 1927 a knapsack unit for field use has been developed especially for chemical eradication work by J. F. Breakey, of the Office of Blister Rust Control. The complete unit, shown in Figure 6, consists of tank, pack board, and pump with hose attachment. The tank is made of 26-gauge galvanized iron and has a capacity of 5½ gallons. It is slightly curved so that it fits naturally and easily to the pack board, to which it is securely fastened by means of two

leather straps. A right-angle support fastened to the pack board beneath the tank prevents vertical shifting. A tight-fitting cap of the automobile gasoline-tank type provides a water-tight seal and is readily removed by hand. A double-action brass pump with handle is attached to the tank by a short length of rubber hose. The pressure within the pump is readily adjusted so that a slow pumping motion delivers a continuous stream of spray. The extent to which the spray is atomized is regulated by the size of the hole in the spraying disk and can be further modified by the pressure that is built up

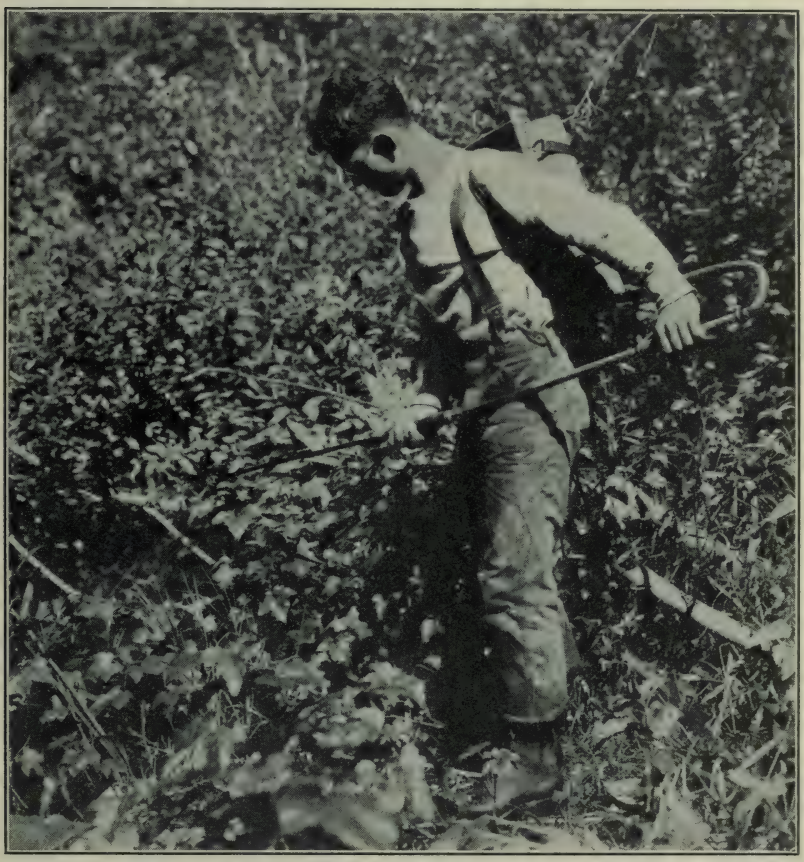

FIGURE 6.—Knapsack tank sprayer with pump attachment, showing the manner in which it is carried by the workman

within the pump by the operator. The complete unit weighs 12¼ pounds when empty and about 60 pounds when filled with chlorate solution.

Initial experiments undertaken in the summer of 1928 show that where Ribes grow in very great profusion power-spraying methods have effected a saving of 56 per cent over hand-pulling methods. (Fig. 7.) Knapsack-spraying methods show a saving of 49 per cent over hand pulling in areas containing fewer Ribes. A test of knapsack and power-spraying methods over identical areas has not been made, and no comparative data on these two methods are available.

It seems certain, however, that both knapsack and power-spraying methods will have a place in any program of eradicating Ribes along forest streams in so far as effective chemicals are available, augmented, of course, by hand-pulling methods where the Ribes are few and somewhat scattered. The hand-spraying method with the knapsack sprayer and the power-spraying method employing the specially devised portable unit are now recommended as field methods for the chemical eradication of *Ribes petiolare*.

It should be observed that details of equipment and working methods for both knapsack and portable power sprayers and also the comparative costs of these methods are still the subject of experimentation. Further changes in the details of equipment and further reduction of costs are expected as the work progresses.

SUMMARY

A number of chemicals were tested on *Ribes petiolare*, *R. lacustre*, and *R. inerme* under varied field conditions in Idaho and Montana to find a cheap, effective chemical for the destruction of these plants in situations where other methods of eradication were unsatisfactory.

These Ribes occur in great abundance in the narrow strip of moist, deep soil found along the streams of the forested areas of the "Inland Empire," where, because of their rôle in the spread of blister rust, they constitute a source of great danger to the adjacent stands of western white pine.

Ribes petiolare, *R. lacustre*, and *R. inerme* layer prolifically under these conditions and thereby develop such a tangled mass of roots that it is impracticable to eradicate them economically by hand pulling or grubbing. The application of chemicals to the ground about the base of the plants growing in these locations is impracticable because the roots are often covered by water and the root systems of individual plants can not be readily located. However, tests of various chemicals applied in this manner to individual plants of *R. lacustre* and *R. inerme* growing in drier situations showed that these species could be effectively killed by such treatment. In the drier situations they develop simple root systems that can be readily located. Of the chemicals tested in these experiments, sodium chlorate 25 per cent aqueous solution applied at the rate of 1 quart per plant and an aqueous solution of sodium hydroxide 4 per cent plus sodium fluoride 5 per cent applied at the same rate gave the best results.

The application of chemicals to the aerial parts of the Ribes species occurring in the stream bottom lands appears to represent the best possibility for their practical eradication. Various concentrations of a large number of chemical sprays were tested by systematically applying them to the leaves and stems of *R. petiolare*, *R. lacustre*, and *R. inerme*. The results showed a wide variation in the toxicity of the different chemicals to these Ribes and indicated that those substances which acted very slowly on the leaves and stems effected more permanent injury than the chemicals that caused quick defoliation and rapid initial injury. Of the chemicals tested in these experiments, sodium chlorate was the most effective spray on the three Ribes species in the "stream-type" location. These plants were decreasingly susceptible to sodium chlorate: *R. petiolare*, *R. lacustre*, and *R. inerme*.

The field experiments show conclusively that one application of from 10 to 50 per cent aqueous solution of sodium chlorate to the leaves and stems of *R. petiolare* kills 96 to 100 per cent of the treated plants. It is concluded that this species of Ribes can be more cheaply and effectively eradicated by this method of treatment than by hand pulling or grubbing the plants. Both *R. lacustre* and *R. inerme* showed considerable resistance to sodium-chlorate sprays, and many of the treated plants reestablished themselves by sprouting from the crown. However, three applications of a 25 per cent solution of sodium chlorate to these species gave from 98 to 100 per cent kill of the treated plants. Fish-oil soap or flake glue, 0.01 to 0.05 per cent by weight of the dry chemical used, added to the sodium-chlorate solution, were found to be satisfactory stickers and spreaders. Best results were obtained by applying sodium chlorate early in the growing season, during dull, cloudy weather. A period of warm, bright weather for a few days after the spray is applied and the presence of

FIGURE 7.—A chemical-eradication crew spraying *Ribes petiolare* and *R. inerme*. Average brush conditions, Bovill, Idaho, 1927

dew at night with comparatively high humidity during the day are favorable for the toxic action of the chemical.

The effect of sodium-chlorate spray on Ribes is first manifested by a slight curling of the leaves. Within a few days the leaves turn brown. The succulent stems of the current year's growth show a marked darkening in color of the epidermis, and brown spots appear in the cambium four or five days after treatment. All succulent stem growth is usually dead at the end of the first week. The older stems show a similar effect from the action of the chemical after 12 to 14 days. Shortly after the effect of the chemical has become noticeable in the cortex of the woody stems, progress of the killing action is manifested by the appearance of a dark-brown coloration in the medullary rays and pith. In the last stages of injury the bark sloughs quite easily from the woody stem and the entire plant is killed to the ground.

Preliminary experiments were undertaken in which several types of spraying equipment and methods of crew spraying were tested. A

3-gallon hand sprayer of the compressed-air type was found to be satisfactory for brushless areas encountered in plot work. Large-scale spraying operations were undertaken by crews of men who used a knapsack tank sprayer with hand pump attached and a specially devised portable power sprayer. Results of large-scale tests showed that power-spraying methods effected a saving of 56 per cent over hand-pulling methods where Ribes occurred in great profusion. In areas where Ribes were less abundant, knapsack spraying was 49 per cent cheaper than hand eradication.

The inflammability of sodium chlorate necessitates extreme care on the part of persons engaged in applying the spray. Clothing should be kept slightly damp at all times and carefully washed at the end of each day's work. Fireproofing and waterproofing of the clothing to be worn by workmen while applying the chlorate spray is desirable and will give a margin of safety. Solutions of sodium chlorate stronger than 10 per cent by weight (0.89 pound per gallon of water) are not recommended for general field use, owing to the risks involved in handling this chemical by those who are not familiar with its chemical properties.

LITERATURE CITED

(1) Åslander, A.
1926. chlorates as plant poisons. (A preliminary report.) Jour. Amer. Soc. Agron. 18:1101–1102.

(2) ———
1927. sulphuric acid as a weed spray. Jour. Agr. Research 34:1065–1091, illus.

(3) Bolley, H. L.
1900. studies upon weeds in 1900. N. Dak. Agr. Expt. Sta. Ann. Rpt. 11:48–56.

(4) Brenchley, W. E.
1925. spraying for weed eradication. Jour. Bath and West and South. Counties Soc. (5) 19:1–20.

(5) Gray, G. P.
1919. tests of chemical means for the control of weeds. Calif. Univ. Pubs., Agr. Sci. 4:67–97.

(6) Latshaw, W. L., and Zahnley, J. W.
1927. experiments with sodium chlorate and other chemicals as herbicides for field bindweed. Jour. Agr. Research 35:757–767, illus.

(7) Long, H. C.
1911. the destruction of weeds by chemical means. an important agricultural problem. Sci. Amer. Sup. 71:76–77, 93–94, illus.

(8) Loyer, [M.]
1923. emploi des chlorates pour la destruction des herbes dans les céréales de printemps. Compt. Rend. Acad. Agr. France 9:957–960.

(9) Rabaté, E.
[1922?] la destruction des mauvaises herbes. 170 p., illus. Paris.

(10) Regan, W. S.
1919. the destruction of ribes by chemical means. Amer. Plant Pest Com. Bul. 4, p. 12.

(11) Schultz, G.
1909. die bekämpfung des unkrautes. drittes stück. ackersenf und hederich. Arb. Deut. Landw. Gesell., Heft 158, 78 p., illus.

(12) Thompson, N. F., and Robbins, W. W.
1926. methods of eradicating the common barberry (berberis vulgaris l.). U. S. Dept. Agr. Bul. 1451, 46 p., illus.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

ANALYSES AND COMPOSITION OF CALIFORNIA LEMON AND ORANGE OILS

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CONTENTS

	Page		Page
Introduction	1	Composition of California lemon and orange oils	12
Analyses of California lemon and orange oils	3	Lemon oil	12
Methods of analyses	3	Orange oil	22
Discussion of results	10	Summary	28
Effect of temperature, water, air, and light on limonene and the citrus oils	11	Literature cited	29

INTRODUCTION

The citrus industry of California, with a total bearing area of 238,000 acres (*9*) [2] in 1927, is confined principally to the southern part of the State (fig. 1), only 2 per cent being in the northern part and 20 per cent in the central part of the State. Practically all the grapefruit acreage, comprising 8,000 acres, and the lemon acreage, 43,000 acres, is in the south. The 1926–27 crop of citrus fruits yielded a total of about 650,000 boxes of grapefruit, 7,700,000 boxes of lemons, and 28,000,000 boxes of oranges.

The harvesting and marketing of the lemon and orange crops vary considerably. There are three varieties of lemons, Lisbon, Eureka, and Villa Franca, the first two predominating. Harvesting is carried on throughout the year, but the largest pickings are made in the spring. The lemons are picked according to size, and although most of them are green, many are yellow or tree ripe. Before being sorted and culled for shipment, the fruit is placed in cold storage for periods ranging from two weeks to several months. No distinction between varieties is made at the packing houses.

There are two principal orange crops: The Valencia, which extends from April to November, and the Washington Navel, from November to May. The oranges, picked only after reaching a maturity standard, are graded and culled upon arrival at the packing house and generally shipped within a few days.

It has been estimated that from 5 to 10 per cent of the citrus crop fails to reach the market standards. This cull fruit is valuable for by-products, and an important industry based on the utilization of

[1] Appreciation is hereby expressed for the assistance of E. M. Chace, chemist in charge, laboratory of fruit and vegetable chemistry, under whose supervision the work was conducted.

[2] Italic numbers in parentheses refer to Literature Cited, p. 29.

cull citrus fruit has developed in southern California in the past 10 years. During the years in which freezes occur or market demands are below the average, still more fruit is utilized for by-products. One of the principal by-products is the citrus oil, but although several hundred thousand pounds of both the expressed and distilled

FIGURE 1.—Map showing by black patches and dots the distribution of the citrus-producing area in California on January 1, 1924

oils have been produced, very little has appeared in the literature pertaining to their analyses and composition. Data on the physical constants are very much needed in order to judge the purity of commercial oils and to compare them with imported oils. The chemical composition is also of considerable interest. The work reported in this bulletin was done to obtain these data.

During the years 1923–1926, inclusive, samples of lemon oil were supplied to this laboratory by a lemon by-products company, and during the same period an orange by-products company furnished samples of Washington Navel and Valencia orange oils.[3] These samples, each weighing about a pound, were from lots of oil commercially produced at the by-products plants by crushing the whole fruit between large rollers, and then separating the oil from the juice by centrifuging. The condition and quantity of fruit in each lot were noted, as well as the district from which it came. The samples, collected in dark bottles, were dried by adding a small quantity of anhydrous sodium sulphate and allowing them to stand in the ice box for several days. They were then filtered and analyzed to determine the physical constants and the citral and the ester content. After this analysis the samples were stored in the ice box, and at the end of each season they were combined in large containers for the determination of their chemical composition.

As these machine-made oils were in contact with the citrus juice during the process of manufacture, it was expected that they would show some variations from the hand-pressed Italian oils. The climatic and soil conditions of California, together with the fact that the fruit had been handled differently from that in Italy, might also affect the composition to a considerable extent. All the oils were from fruit from the southern counties, as there are no by-products plants in the north.

ANALYSES OF CALIFORNIA LEMON AND ORANGE OILS

METHODS OF ANALYSES

The methods given in the Journal of the Association of Official Agricultural Chemists were used in the analyses of the oils (*2, p. 355*). The specific gravity, however, was determined at $\frac{25°C}{25°C}$ as recommended in the United States Pharmacopœia. These results may be calculated to $\frac{15.6°}{15.6°}$ by adding 0.0054, and to $\frac{20°}{20°}$ by adding 0.0025. If desired, the results at $\frac{20°}{20°}$ may be calculated to $\frac{20°}{4°}$ by multiplying by 0.99823, the density of water at 20°.

The total solids [4] were determined by evaporating 10 cubic centimeters of the sample measured at 20° nearly to dryness on a water bath, then transferring to a water-jacketed oven and drying at the temperature of boiling water for two and one-half hours.

Citral was determied by the Kleber method and also by the Parker and Hiltner method (*13*). The latter, a modification of the old official Hiltner method, is now official (*3, 18*).

As the California orange oils are more deeply colored than the imported oils, it was necessary in using the Hiltner method to decolorize them with charcoal, in order to compare them with the standard citral solution. This was accomplished by diluting 4 grams of oil to 50 cubic centimeters with alcohol, and placing 5 cubic centimeters of the diluted oil in a 50 cubic centimeter Erlenmeyer flask with about 15 cubic centimeters of alcohol and enough charcoal to decolorize.

[3] The oils used in this investigation were supplied by the Exchange Lemon Products Co., Corona, Calif., and the Exchange Orange Products Co., Ontario, Calif.

[4] Total solids is here used for the substance designated as evaporation residue by Gildemeister and Hoffmann (*6, v. 3, p. 50, 68*).

It was then filtered and washed into a 50 cubic centimeter flask, 10 cubic centimeters of the metaphenylenediamine hydrochloride solution was added, and the whole was made up to mark with alcohol.

The aldehyde in orange oil is decylic, although as a rule it is reported as citral. As metaphenylenediamine hydrochloride apparently does not react quantitatively with decylic aldehyde, the results by the Hiltner method are always much lower than by the phenylhydrazine method (Kleber method). The latter method as used in this work requires that the phenylhydrazine shall stand with the oil for half an hour. This is long enough for lemon oil, but as reported by Gildemeister and Hoffmann (*6, v. 3, p. 56*), two hours are necessary for orange oil, as decylic aldehyde reacts more slowly than citral. In tests made with several samples of orange oil the oils showed about 1 per cent of aldehyde as citral in half an hour, but yielded 0.2 per cent more when they were allowed to stand for two hours with the phenylhydrazine.

Although both α and β pinene were identified in the lemon oil, the official pinene test gave negative results because it is not delicate enough to reveal mere traces. No pinene was found in the orange oil.

The saponifiable substances (esters) were determined by the following unpublished method of A. F. Seeker and W. E. Kirby: Place 4 grams of oil, 25 cubic centimeters of 95 per cent alcohol, and 1 cubic centimeter of 50 per cent hydroxylamine hydrochloride in a separatory funnel. Titrate to a faint pink with a 4 per cent alcoholic solution of potassium hydroxide, using phenolphthalein as indicator. Discharge the color at once by adding 1 drop of a 20 per cent solution of hydroxylamine hydrochloride, add 25 cubic centimeters of benzene, purified as directed below, and shake. Then add 50 cubic centimeters of a saturated salt solution and shake again vigorously. Allow the mixture to separate, draw off and discard the salt solution, and wash three times more in the same manner, using each time 25 cubic centimeters of salt solution. Finally wash with 4 cubic centimeters of water, and after drawing off the water, run the benzene solution into a 200 cubic centimeter Erlenmeyer flask. Rinse the separatory funnel once with 25 cubic centimeters of alcohol and add this alcohol to the solution in the Erlenmeyer flask.

Add sufficient approximately tenth normal alcoholic potassium hydroxide to make the mixture neutral to phenolphthalein, and then add exactly 30 cubic centimeters more. Boil under a reflux condenser for one hour, cool, and titrate with a tenth normal aqueous solution of hydrochloric acid. Deduct the volume of acid required for this titration from the quantity required to titrate a blank conducted by refluxing for one hour a mixture containing 25 cubic centimeters each of benzene and alcohol and 30 cubic centimeters of the approximately tenth normal alcoholic potassium hydroxide. One cubic centimeter of tenth normal hydrochloric acid is equivalent to 0.0196 gram of the esters linalyl and geranyl acetates.

Most grades of benzene on the market require purification for this purpose. It may be purified as follows: Reflux 2 liters of the benzene for two hours with sodium ethylate (3 grams of metallic sodium dissolved in 100 cubic centimeters of 95 per cent alcohol). Then distill, rejecting the first and last portions, and wash the distillate in a separatory funnel twice with distilled water to remove alcohol and other soluble substances.

The Seeker-Kirby method has been found to determine about 90 to 95 per cent of known amounts of linalyl acetate which had been

added to mixtures of citral and terpenes. It is quite satisfactory to use for comparison of the California and imported oils. According to Gildemeister and Hoffmann (*6, v. 1, p. 571*) esters in oils which contain aldehydes can not be determined by the ordinary quantitative saponification method, as, owing to the decomposition of the aldehyde, alkali is consumed. This consumption increases with the length of time of the reaction. In the Seeker-Kirby method the aldehyde is removed with the hydroxylamine hydrochloride.

The results of the analyses of the oils are given in Tables 1, 2, and 3. The pinene tests, made on the first 64 samples of lemon oil, on the first 21 samples of Valencia orange oil, and on the first 3 samples of Washington Navel orange oil, were negative. The determination of esters made on the first 21 samples of Valencia oil, combined according to counties, showed the following averages: Los Angeles, 1.03 per cent; Orange, 1.08 per cent; San Bernardino, 1.08 per cent. Average analyses of distilled oils obtained from the first 11 lots of Valencia oranges are included in Table 2. These oils were produced at the plant by steam distilling the residue, after removal of the juice and expressed oil. These combined oils contained 0.49 per cent of esters.

TABLE 1.—*Analyses of California lemon oils*

Source of fruit (county) and number of samples	Quantity of fruit	Specific gravity	Total solids	Refractive index[1]			Optical rotation[1]			Citral		Esters
				Original	10 per cent distillate	Difference	Original	10 per cent distillate	Difference	Kleber	Hiltner	
							°	°	°			
Ventura (14 samples):	*Tons*		*P. ct.*							*P. ct.*	*P. ct.*	*P. ct.*
Minimum	16.7	0.8486	2.27	1.4739	1.4727	0.0010	52.71	47.58	2.92	2.7	2.0	1.85
Maximum	27.5	.8525	4.28	1.4749	1.4733	.0016	66.17	63.25	5.82	3.7	3.7	3.04
Average	21.5	.8504	3.02	1.4744	1.4731	.0013	59.55	55.02	4.52	3.2	2.8	2.46
San Bernardino (2 samples):												
Minimum	18.0	.8482	2.24	1.4738	1.4726	.0012	62.28	58.67	3.61	2.1	1.6	1.76
Maximum	20.0	.8511	3.19	1.4747	1.4732	.0015	65.20	60.90	4.30	2.8	2.5	3.04
Average	19.0	.8496	2.72	1.4742	1.4729	.0014	63.74	59.78	3.96	2.4	2.0	2.40
Los Angeles (19 samples):												
Minimum	10.0	.8481	2.01	1.4738	1.4726	.0011	60.48	55.91	1.80	2.3	1.8	1.96
Maximum	28.1	.8511	4.52	1.4748	1.4732	.0017	69.07	64.91	5.97	3.2	2.9	2.84
Average	20.9	.8493	3.02	1.4742	1.4729	.0013	64.29	60.14	4.15	2.6	2.2	2.24
Riverside (10 samples):												
Minimum	14.7	.8475	2.21	1.4738	1.4727	.0010	63.11	57.00	3.74	2.0	1.4	1.86
Maximum	30.6	.8506	3.86	1.4745	1.4733	.0014	70.18	65.74	6.11	2.6	2.6	2.50
Average	22.1	.8487	2.96	1.4742	1.4730	.0012	65.80	60.98	4.82	2.3	2.0	2.12
San Diego (12 samples):												
Minimum	15.2	.8488	2.22	1.4742	1.4729	.0011	53.12	46.47	2.92	2.5	1.6	1.76
Maximum	21.6	.8517	3.48	1.4746	1.4732	.0016	67.55	61.63	6.65	5.2	2.9	3.12
Average	17.8	.8501	2.66	1.4744	1.4730	.0013	61.76	57.13	4.64	2.8	2.2	2.62
Santa Barbara (2 samples):												
Minimum	17.5	.8506	3.76	1.4742	1.4730	.0012	54.24	47.44	6.79	3.0	2.4	1.91
Maximum	24.1	.8515	4.43	1.4742	1.4730	.0012	54.93	48.14	6.80	3.1	2.7	2.34
Average	20.8	.8510	4.10	1.4742	1.4730	.0012	54.58	47.79	6.80	3.0	2.6	2.12
Orange (14 samples):												
Minimum	16.6	.8489	2.08	1.4738	1.4728	.0005	59.23	53.82	2.89	2.2	1.9	2.21
Maximum	26.1	.8516	4.07	1.4748	1.4737	.0015	66.73	61.99	6.79	3.3	3.1	2.94
Average	20.9	.8498	2.94	1.4743	1.4731	.0011	62.13	57.41	4.73	2.9	2.4	2.50
Seven counties (73 samples):												
Minimum	10.0	.8475	2.01	1.4738	1.4726	.0005	52.71	46.47	1.80	2.0	1.4	1.76
Maximum	30.6	.8525	4.52	1.4749	1.4737	.0017	70.18	65.74	6.80	3.7	3.7	3.12
Average	20.3	.8497	2.96	1.4743	1.4730	.0013	62.48	57.90	4.57	2.8	2.3	2.38

[1] Wherever used in this bulletin, refractive index and optical rotation refer to sodium light and 20°C; that is, $n\frac{20°}{D}$ and $\alpha\frac{20°}{D}$. Determinations of specific gravity were always made at $\frac{25°C}{25°C}$.

TABLE 2.—*Analyses of California Valencia orange oils*

County or season and number of samples	Quantity of fruit	Specific gravity	Total solids	Refractive index			Optical rotation			Citral		Esters
				Original	10 per cent distillate	Difference	Original	10 per cent distillate	Difference	Kleber	Hiltner	
Orange County (23 samples):	*Tons*		*P. ct.*				°	°	°	*P. ct.*	*P. ct.*	*P. ct.*
Minimum	5.0	0.8425	2.74	1.4728	1.4719	0.0009	96.12	97.94	0.56	1.1	0.16	0.49
Maximum	12.4	.8482	5.87	1.4745	1.4726	.0021	98.50	99.88	−3.47	1.8	.36	1.76
Average	9.2	.8448	4.22	1.4736	1.4722	.0014	97.29	99.17	−1.87	1.4	.24	1.03
Los Angeles County (36 samples):												
Minimum	4.1	.8413	1.93	1.4728	1.4718	.0007	95.71	98.21	.96	1.0	.13	.35
Maximum	13.6	.8460	4.82	1.4741	1.4727	.0020	99.58	100.44	−3.05	2.2	.32	1.37
Average	9.0	.8434	3.15	1.4734	1.4723	.0011	98.04	99.19	−1.14	1.4	.22	.81
San Bernardino County (4 samples):												
Minimum	3.6	.8425	2.55	1.4735	1.4723	.0010	97.81	99.19	−1.10	0.8	.14	.94
Maximum	8.3	.8464	6.26	1.4746	1.4725	.0023	98.92	100.02	−1.94	1.2	.23	1.08
Average	5.8	.8447	4.29	1.4742	1.4724	.0017	98.22	99.64	−1.42	1.0	.17	1.06
All counties (63 samples):												
Minimum	4.1	.8413	1.93	1.4728	1.4718	.0007	95.71	97.94	.96	.8	.13	.44
Maximum	13.6	.8482	6.26	1.4746	1.4727	.0023	99.58	100.44	−3.47	2.2	.36	1.76
Average	8.8	.8440	3.61	1.4735	1.4723	.0013	97.78	99.21	−1.43	1.4	.22	.83
Distilled (11 samples)												
Average	-----	.8406	1.46	1.4722	1.4720	.0002	99.28	98.87	.41	1.2	.21	.49
Season 1923 (21 samples):												
Minimum	3.6	.8418	1.93	1.4732	1.4720	.0007	95.71	98.21	−.54	0.8	.15	-----
Maximum	11.0	.8467	6.26	1.4746	1.4727	.0023	98.64	100.44	−3.47	1.8	.35	-----
Average	7.0	.8439	3.93	1.4737	1.4723	.0014	97.46	99.34	−1.88	1.3	.23	1.05
Season 1924 (11 samples):												
Minimum	-----	.8425	2.74	1.4728	1.4718	.0009	96.12	98.62	−.83	1.3	.22	.49
Maximum	-----	.8449	4.81	1.4731	1.4721	.0012	98.21	99.60	−3.20	2.2	.36	1.37
Average	-----	.8438	3.75	1.4730	1.4720	.0010	97.16	99.10	−1.94	1.7	.28	.96
Season 1925 (31 samples):												
Minimum	5.0	.8413	2.07	1.4730	1.4720	.0007	95.99	97.94	.96	1.0	.13	.35
Maximum	13.6	.8482	5.65	1.4742	1.4726	.0019	99.58	100.02	−3.33	1.8	.25	1.76
Average	9.9	.8442	3.35	1.4736	1.4724	.0012	98.21	99.16	−.94	1.4	.19	.78

TABLE 3.—*Analyses of California Washington Navel orange oils*

County or season and number of samples	Quantity of fruit	Specific gravity	Total solids	Refractive index			Optical rotation			Citral		Esters
				Original	10 per cent distillate	Difference	Original	10 per cent distillate	Difference	Kleber	Hiltner	
Los Angeles County (18 samples):	*Tons*		*P.ct.*				°	°	°	*P.ct.*	*P.ct.*	*P.ct.*
Minimum	1.3	0.8419	1.49	1.4731	1.4723	0.0008	94.18	97.79	0.41	0.6	0.12	0.59
Maximum	12.4	.8503	8.17	1.4748	1.4727	.0024	99.32	99.59	−4.71	1.0	.27	2.58
Average	5.0	.8456	4.75	1.4738	1.4724	.0014	96.93	98.77	−1.84	.8	.19	1.50
San Bernardino County (7 samples):												
Minimum	1.0	.8425	2.20	1.4732	1.4723	.0009	95.29	98.05	.00	.7	.14	.49
Maximum	11.6	.8489	6.84	1.4746	1.4727	.0020	98.77	99.31	−3.74	.9	.21	2.11
Average	5.4	.8456	4.41	1.4738	1.4724	.0014	96.76	98.64	−1.88	.8	.17	1.27
Riverside County (6 samples):												
Minimum	1.1	.8426	2.31	1.4732	1.4722	.0009	95.84	97.93	.69	.7	.16	.54
Maximum	11.6	.8478	6.26	1.4742	1.4727	.0017	98.62	98.91	−2.92	.9	.23	2.22
Average	7.2	.8449	4.02	1.4736	1.4724	.0012	97.12	98.60	−1.48	.8	.19	1.18
All counties (31 samples):												
Minimum	1.0	.8419	1.49	1.4731	1.4721	.0008	94.18	97.51	.69	.6	.12	.49
Maximum	12.4	.8503	8.17	1.4748	1.4727	.0024	99.32	99.59	−4.71	1.0	.27	2.58
Average	5.5	.8455	4.53	1.4738	1.4724	.0013	96.93	98.71	−1.78	.8	.19	1.38
Season 1924 (3 samples):												
Minimum	-----	.8423	2.07	1.4731	1.4721	.0008	98.21	98.49	−.14	.7	.22	.69
Maximum	-----	.8444	3.94	1.4734	1.4723	.0013	98.91	99.05	−.56	.9	.27	.98
Average	-----	.8433	2.77	1.4732	1.4722	.0010	98.45	98.77	−.32	.8	.24	.82
Season 1925 (10 samples):												
Minimum	5.5	.8419	1.49	1.4731	1.4722	.0008	95.99	97.93	.69	.6	.12	.49
Maximum	12.4	.8458	5.05	1.4736	4.4727	.0011	99.32	99.32	−2.92	.9	.21	1.22
Average	9.3	.8430	2.58	1.4733	1.4723	.0010	98.13	98.80	−.67	.7	.16	.72
Season 1926 (18 samples):												
Minimum	1.0	.8449	4.40	1.4737	1.4723	.0013	94.18	97.51	−1.65	.8	.15	1.37
Maximum	8.7	.8503	8.17	1.4748	1.4727	.0024	96.96	99.59	−4.71	1.0	.25	2.58
Average	3.4	.8472	5.91	1.4741	1.4725	.0016	96.01	98.65	−2.64	.9	.19	1.85

Table 4 contains summaries of published analyses of pure Italian hand-pressed lemon oils made by Chace (*5*), for comparison with the California machine-made oils, and also unpublished data on Italian orange oils as supplied by Mr. Chace.

Table 5 contains the analyses of hand-pressed oils made by the Italian 2-piece method and laboratory machine-made oils produced from the same lots of peels. The oil machine (*15*) developed by W. E. Sutton of the laboratory of fruit and vegetable chemistry handles about 300 pounds of peel an hour, and has given satisfactory yields with lemon peel.

TABLE 4.—*Analyses of Italian lemon and orange oils*

Source and number of samples	Specific gravity	Refractive index			Optical rotation			Total aldehydes (sulphite method)	Citral	
		Original	10 per cent distillate	Difference	Original	10 per cent distillate	Difference		Kleber	Hiltner
					°	°	°	*Per cent*	*Per cent*	*Per cent*
LEMON OILS[1]										
Authentic samples collected in factories in Sicily, 1907–08 (15 samples):										
Minimum	0.8503	1.4745	1.4726	0.0019	57.96	53.70	3.16	4.35	-----	-----
Maximum	.8542	1.4758	1.4730	.0028	63.03	58.75	5.70	7.03	-----	-----
Average	.8526	1.4751	1.4727	.0024	59.97	55.74	4.23	5.57	-----	-----
Collected from bowls of workmen in factories in Sicily, 1907–08 (130 samples):										
Minimum	.8503	1.4743	1.4720	.0017	54.16	49.08	1.01	4.07	-----	-----
Maximum	.8552	1.4758	1.4735	.0028	66.28	63.98	6.17	6.43	-----	-----
Average	.8522	1.4748	1.4726	.0022	60.49	56.69	3.83	5.30	-----	-----
Collected from bowls of workmen in factories in Sicily, 1909–10 (50 samples):										
Minimum	.8508	1.4740	1.4720	.0017	54.68	50.71	0.18	3.8	3.4	2.6
Maximum	.8539	1.4753	1.4732	.0028	63.62	62.87	4.58	5.4	5.2	5.3
Average	.8522	1.4747	1.4725	.0023	59.18	56.77	2.74	4.8	4.5	4.2
ORANGE OILS										
Collected from bowls of workmen in factories in Sicily, 1907–08 (6 samples):										
Minimum	0.8419	1.4725	1.4710	0.0010	96.9	96.3	0.6	2.6	-----	-----
Maximum	.8447	1.4730	1.4716	.0018	99.6	99.1	−1.0	3.3	-----	-----
Average	.8432	1.4727	1.4713	.0014	98.4	98.4	0.0	2.8	-----	-----
Collected from bowls of workmen in factories in Sicily, 1909 (22 samples):										
Minimum	.8435	1.4723	1.4712	.0008	92.03	95.90	−0.42	1.58	1.47	0.43
Maximum	.8476	1.4737	1.4723	.0021	98.44	99.40	−6.53	2.64	2.89	0.71
Average	.8447	1.4729	1.4717	.0012	97.19	98.56	−1.35	2.03	2.12	0.53

[1] Data derived from Table XI, U. S. Dept. Agr., Bur. Chem. Circ. 46, The Occurrence of Pinene in Lemon Oil.

97742°—32——2

TABLE 5.—*Analyses of laboratory machine-made and hand-pressed lemon and orange oils*

LEMON OILS

No.	Date	Description of sample	Weight of peel	Amount of oil	Yield of oil per ton of peel	Specific gravity	Total solids	Refractive index			Optical rotation			Citral		Esters
								Original	10 per cent distillate	Difference	Original	10 per cent distillate	Difference	Kleber	Hiltner	
			Pounds	*Ounces*	*Pounds*		*P. ct.*				°	°	°	*P. ct.*	*P. ct.*	*P. ct.*
72	May 12, 1926	Factory sample No. 72 of Table 1				0.8502	3.00	1.4744	1.4734	0.0010	61.31	57.42	3.89	3.3	2.1	2.35
72M	May 13, 1926	Peel from same lot as No. 72, made in small laboratory machine	300			.8514	3.95	1.4746	1.4733	.0013	61.31	57.18	4.13	3.6	2.5	2.45
73	May 25, 1926	Factory sample No. 73 of Table 1				.8489	3.76	1.4742	1.4737	.0005	60.61	53.82	6.79	3.0	2.7	2.21
73M	May 26, 1926	Peel from same lot as No. 73, made in small laboratory machine	300			.8511	4.20	1.4744	1.4731	.0013	60.19	55.34	4.85	3.5	2.8	2.70
1M	July 22, 1926	Made in small laboratory machine	92	6.1	8.4	.8537	3.93	1.4749	1.4732	.0017	56.73	49.93	6.80	4.2	2.5	2.50
2M	Aug. 19, 1926	do	100	4.0	5.0	.8513	3.00	1.4747	1.4731	.0016	57.98	52.57	5.41	3.7	2.9	2.74
3M	Nov. 4, 1926	Made in large laboratory machine	450	13.8	3.8	.8511	3.92	1.4743	1.4730	.0013	60.06	57.42	2.64	2.7	2.0	2.99
4M	Dec. 2, 1926	do	128	6.0	5.7	.8508	4.95	1.4746	1.4733	.0013	59.51	58.12	1.39	3.3	2.5	3.18
5M	Jan. 27, 1927	do	1,038	61.0	7.34	.8495	3.52	1.4746	1.4731	.0015	67.52	67.13	.39	2.5	2.1	2.70
5H	do	Peel from same lot as 5M, hand pressed	85	7.0	10.34	.8505	3.76	1.4746	1.4731	.0015	67.69	66.05	1.64	3.0	2.5	2.55
6M	Mar. 12, 1927	Made in large laboratory machine	815	54.6	8.34	.8499	5.27	1.4746	1.4731	.0015	64.36	60.89	3.47	3.5	2.7	2.30
6H	do	Peel from same lot as 6M, hand pressed	74	6.6	11.1	.8517	6.27	1.4751	1.4732	.0019	63.52	62.28	1.24	3.8	3.0	3.04
7M	Mar. 21, 1927	Made in large laboratory machine	1,555	83.8	6.76	.8494	4.29	1.4743	1.4729	.0014	67.69	65.05	2.64	2.3	2.0	2.50
7H	do	Peel from same lot as 7M, hand pressed	79	4.6	7.34	.8517	7.01	1.4747	1.4729	.0018	66.02	66.30	−.28	2.6	2.3	3.48
		Average of laboratory machine-made oils (9 samples)				.8508	4.11	1.4746	1.4731	.0015	61.71	58.18	3.53	3.3	2.4	2.68
		Average of hand-pressed oils (3 samples)				.8516	5.68	1.4748	1.4731	.0017	65.74	64.88	.86	3.1	2.6	3.02

ORANGE OILS

1H	Apr. 2, 1926	Hand pressed Washington Navel oil	180	2.1	1.44	0.8455	8.30	1.4737	1.4724	0.0013	93.90	99.59	−5.69	1.3	0.15	1.57
2H	Apr. 8, 1926	do	190	2.5	1.69	.8462	6.76	1.4742	1.4724	.0018	95.44	99.73	−4.29	1.0	.12	1.32
3H	Apr. 16, 1926	do	200	3.5	2.2	.8455	7.82	1.4741	1.4723	.0018	94.04	100.00	−5.96	1.3	.16	1.47
4M	June 4, 1926	Valencia oil made in small laboratory machine	300			.8428	2.38	1.4731	1.4721	.0010	98.75	99.03	−.28	1.6	.27	.54
5M	Mar. 9, 1927	Washington Navel oil made in large laboratory machine	385	3.2	1.04	.8439	4.10	1.4734	1.4725	.0009	97.51	98.89	−1.38	1.3	.29	1.08
5H	do	Peel from same lot as 5M, hand pressed	51	.4	.9	.8438	4.60	1.4735			96.40				.25	1.32
6M	Apr. 6, 1927	Seedling oil made in large laboratory machine	1,405	11.5	1.03	.8453	7.02	1.4741	1.4725	.0016	95.70	100.28	−4.58	.7	.12	1.23
6H	do	Peel from same lot as 6M, hand pressed	45	.3	.9	.8470		1.4742			92.93				.12	
7M	Apr. 12, 1927	Seedling oil made in large laboratory machine	1,670	20.5	1.53	.8453	4.59	1.4738	1.4725	.0013	97.78	100.00	−2.22	.9	.18	1.19
7H	do	Peel from same lot as 7M, hand pressed	96	1.4	1.8	.8481	8.05	1.4744	1.4723	.0021	95.01	100.29	−5.28		.25	1.86
8M	May 11, 1927	Valencia oil made in large laboratory machine	2,025	38.7	2.39	.8444	5.10	1.4735	1.4723	.0012	96.13	99.31	−3.18	1.0	.20	.98
8H	do	Peel from same lot as 8M, hand pressed	85	3.2	4.71	.8453	5.24	1.4734	1.4722	.0012	95.29	99.31	−4.02	1.7	.26	1.62

DISCUSSION OF RESULTS

LEMON OIL

In Table 1 the averages of results, by counties, show a noticeable variance only in the lower optical rotation and higher percentage of citral from Ventura and Santa Barbara Counties, which adjoin. The highest average optical rotation is found in Riverside County and the next highest in Los Angeles County. Otherwise the averages are fairly uniform. In optical rotation and citral the difference between the maximum and minimum of all the samples is large, the difference in optical rotation being 17.47° and the difference in percentage of citral determined according to the Kleber method being 1.7. Comparison of the California machine-made lemon oils given in Table 1 with the Italian hand-made lemon oils in Table 4 shows the Italian oils to be about 0.0025 higher in specific gravity and 0.0005 higher in refractive index, whereas in optical rotation they are about 2.4° lower. The Italian oils contain more citral, the difference in percentage being 1.7 according to the Kleber method and 1.9 according to the Hiltner method. Fifty-nine samples of Italian lemon oil imported at New York averaged 2.5 per cent total solids; the California oils averaged 2.96 per cent—that is, a difference of 0.5. Fifty other imported samples averaged 3.01 per cent esters by the Seeker and Kirby method, being higher by about 0.6 than the California oils, which averaged 2.38 per cent. Comparison of the laboratory machine-made lemon oils 72M and 73M (Table 5) with the factory machine-made oils 72 and 73 shows that they are about the same except that the citral is higher in the laboratory machine-made oils. The average of citral and of esters in the 9 laboratory machine-made oils (Table 5) is higher than the average of these in the factory samples (Table 1), the difference in percentage being 0.5 (Kleber method) and 0.3, respectively. The hand-pressed oils are from 0.3 to 0.5 per cent higher in citral than the corresponding laboratory machine-made oil. Only one of the oils, No. 1M, contained more than 4 per cent citral. By the Kleber method the average percentage of citral in the 3 hand-made oils was less than that in the Italian oils by 1.4.

ORANGE OIL

The averages by counties of the Valencia oils, shown in Table 2, are uniform, except that the refractive index is higher and the citral content lower in the oils from San Bernardino than in those from the other two counties. The tabulation by seasons shows even more uniformity than by counties, although the refractive index is lower and the citral content higher for 1924. The 11 samples of distilled oil resemble the 10 per cent distillate from the cold-pressed oils, containing, however, nearly as much aldehyde as the cold-pressed oils and two-thirds the quantity of esters.

The averages by counties of the Washington Navel orange oils, in Table 3, are exceptionally uniform so that no striking differences are noted. The tabulation by seasons, however, shows that the excessive quantity of total solids during 1926 produced an average specific gravity 0.0041 higher and a refractive index 0.0009 higher than those in 1924 and 1925. The optical rotation in 1926 is lower by about 2°, and the ester content is more than 1 per cent higher. The ester content appears to vary with the total solids, although not proportionately.

Comparison of the averages of the Valencia and Washington Navel oils (Tables 2 and 3) shows that the content of aldehydes in the Valencia

oil is 0.6 per cent higher than that in the Washington Navel oil by the Kleber method and 0.02 per cent higher by the Hiltner method, and the content of esters is about 0.5 per cent lower. The physical constants, however, are fairly uniform. The Italian orange oils shown in Table 4 have a refractive index about 0.0008 lower than that of the California oils, and the percentage content of citral determined by the Kleber method is higher than that in the Valencia oil by about 0.7. The Hiltner method shows about twice as much citral in the Italian oils. Twenty-seven samples of Italian oil imported at New York averaged 2.8 per cent of total solids, about 0.8 per cent less than the Valencia oils and 1.7 per cent less than the Washington Navel. Imported oils yielded about 0.5 per cent of esters, considerably less than the California oils. No striking differences are noted upon comparing the laboratory machine-made and hand-pressed oils shown in Table 5 with the factory machine-made samples in Tables 2 and 3.

EFFECT OF TEMPERATURE, WATER, AIR, AND LIGHT ON LIMONENE AND THE CITRUS OILS

Ogston and Moore (*12*) reported that a sample of Italian lemon oil held in a sealed container for 10 years showed very little difference in analysis and no material change in quality. Konnerth (*10*) found that lemon and orange oils kept well when stored in bottles under nitrogen.

In order to determine the effect of temperature and air on the California oils, 20 cubic centimeters each of lemon and orange oil previously dried over anhydrous sodium sulphate were placed in Erlenmeyer flasks closed with corks containing a small opening to permit air to enter. One set was allowed to remain in the laboratory, while the other was placed in the refrigerator, the temperature of which ranged from 2° to 10° C., and which of course was dark. During the storage period of 20 months, eight determinations of the refractive index and optical rotation were made at irregular intervals. The former gradually increased, and the latter decreased, except in the orange-oil sample in the ice box, which showed practically no change. The viscosity also increased until the oils had a sirupy consistence. During the same period, both clear and amber bottles filled full with 60 cubic centimeters of the oils were sealed and held at the two temperatures. At the end of the 20 months all samples were analyzed. The results are shown in Table 6. The specific gravity had increased to more than 1 in the open samples at room temperature, and the acid values of the lemon oil had multiplied 32 times and that of the orange 35 times. On the other hand, all sealed samples remained unchanged, the slight differences in the results at the end of the 20-month period coming within the error of analysis. The color and odor also remained unchanged. These results show that if the oils are kept at room temperature in colorless bottles the exclusion of air alone is all that is necessary to prevent change. In the open orange-oil sample held in the ice box, the temperature was evidently low enough to prevent oxidation.

TABLE 6.—*Effect of temperature, air, and light on lemon oil and orange oil and limonene from lemon oil; and the effect of water on limonene*

Oil treatment	Specific gravity			Refractive index			Optical rotation			Acid value		
		After 20 months			After 20 months			After 20 months			After 20 months	
	Original	At room temperature	In ice box	Original	At room temperature	In ice box	Original	At room temperature	In ice box	Original	At room temperature	In ice box
							°	°	°			
Lemon oil	0.8511			1.4744			60.20			0.9		
20 c. c. exposed to air in open Erlenmeyer flask		1.0250	0.9279		1.4980	1.4851		22.21	45.35		29.2	8.8
60 c. c. sealed in clear bottle		.8511	.8512		1.4743	1.4744		59.92	59.92		.8	.8
60 c. c. sealed in amber bottle		.8516			1.4744			59.64			.9	
Orange oil	.8435			1.4733			99.03			.7		
20 c. c. exposed to air in open Erlenmeyer flask		1.0328	.8445		1.4980	1.4735		35.09	98.37		24.4	.7
60 c. c. sealed in clear bottle		.8436	.8435		1.4734	1.4733		98.75	98.61		.6	.6
60 c. c. sealed in amber bottle		.8439			1.4734			98.61			.6	
Limonene	.8450			1.4733			69.63			.1		
20 c. c. exposed to air in open Erlenmeyer flask		1.0721	.9809		1.5025	1.4907		15.81	36.33		37.8	17.4
60 c. c. sealed in clear bottle		.8444	.8445		1.4733	1.4734		69.35	69.35		.1	.1
60 c. c. sealed in amber bottle		.8451			1.4732			69.49			.1	
105 c. c. sealed in amber bottle with 25 c. c. water		.8444	.8448		1.4733	1.4733		70.32	70.32		.1	.1
85 c. c. exposed to dry air in clear bottle		.9884	.9489		1.4943	1.4886		33.57	43.41		14.3	8.9
85 c. c. exposed to dry air in amber bottle		.9907			1.4945			32.59			14.4	
85 c. c. with 20 c. c. water, exposed to air in clear bottle		.9549	.9461		1.4887	1.4878		37.03	43.00		39.2	25.7

At the same time that the lemon and orange oil samples were stored, samples of limonene from lemon oil were set aside under the same conditions, and with additional samples in clear and amber bottles open to the air, which was dried, however, by entering through calcium chloride tubes. Also, bottles filled with 105 cubic centimeters of limonene and 25 cubic centimeters of water were sealed and stored. One containing limonene and water was left open to the air. The results of the analysis at the end of 20 months as given in Table 6 showed that the limonene was unaffected in the presence of water if air was excluded. Marked changes occurred in the presence of dry air. Water and air together appeared to cause the greatest increase in acid value as shown by those samples having the large acid values in Table 6. As in the lemon and orange oils, all sealed samples remained unchanged.

COMPOSITION OF CALIFORNIA LEMON AND ORANGE OILS

LEMON OIL

DISTILLATION OF LOT 1

The first 26 samples of lemon oil were combined, making a total of 6,860 grams, and called lot 1. The physical constants were: $d\frac{25°C.}{25°C.}=0.8499$, $a\frac{20°}{D}=61.72°$, $n\frac{20°}{D}=1.4742$. The composition was:

Total solids, 3.87 per cent; citral (Kleber), 2.8 per cent; (Hiltner), 2.3 per cent.

A general outline of the method used for the identification of the constituents of the oil is shown diagrammatically in Figure 2.

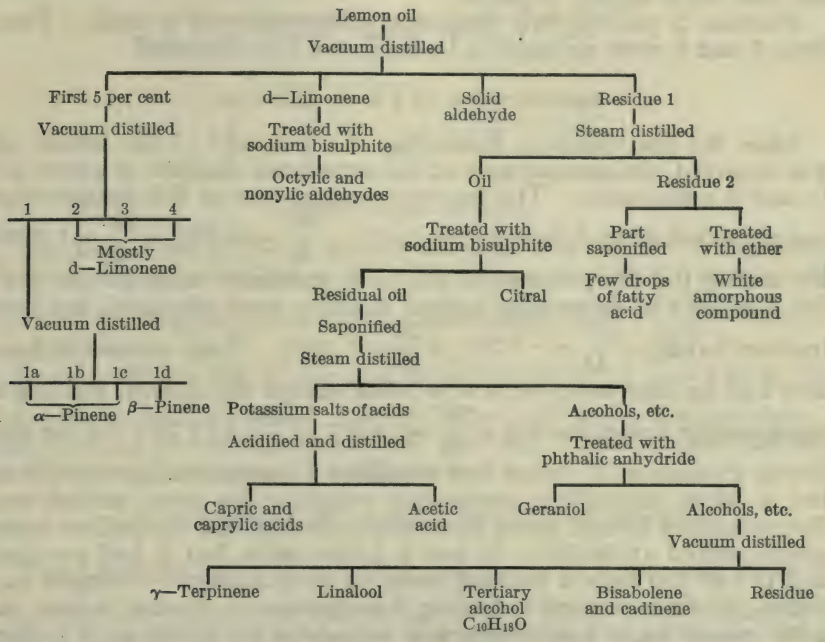

FIGURE 2.—General outline of method used for identification of constituents of lemon oil

The oil was distilled in 1,600-gram batches under a pressure of 3 millimeters with a 15-disk Young fractionating column and a Bogert receiver. The first fractions, consisting of 5 per cent by volume of each lot, were combined and refractionated several times, the four fractions in Table 7 being finally separated.

TABLE 7.—*Fractions obtained from the first 5 per cent fraction of lot 1 of lemon oil*

Fraction	Weight	Optical rotation	Refractive index
	Grams	°	
1	37	6.24	1.4723
2	51	16.51	1.4730
3	132	52.44	1.4739
4	60	76.16	1.4749

IDENTIFICATION OF α-PINENE

About four-fifths of the nitrosochloride crystals (*6, v. 1, p. 296*) obtained from 10 cubic centimeters of fraction 1 (Table 7) were the characteristic pinene crystals, the remainder being limonene. These mixed crystals and the compounds formed from them had the following melting points: Nitrosochloride, 98° to 99°; nitrol-benzylamine, 121° to 122°; and the nitrol piperidine, 119° to 120°. The

melting points of the corresponding α-pinene compounds are: Nitrosochloride, 103°, nitrol-benzylamine, 122° to 123°, and nitrol piperidine, 118° to 119°. The melting points, therefore, together with the fact that β-pinene does not form nitrosochloride crystals, show that the fraction is largely α-pinene.

Fraction 2 yielded only limonene nitrosochloride crystals. Fractions 3 and 4 were assumed to be limonene and discarded.

IDENTIFICATION OF A SOLID ALDEHYDE

After the first fraction, consisting of 5 per cent of the lemon oil, was removed, the greater part of the remainder distilled at about 45° C. and 3 millimeters. The fraction coming over at this temperature and pressure had the following constants: $\alpha\frac{20°}{D}=68.39°$, $n\frac{20°}{D}=1.4733$. By raising the temperature of the bath gradually from 70° to 120°, five fractions of decreasing optical rotation were obtained, the final fraction having $\alpha\frac{20°}{D}=-8.74°$, $n\frac{20°}{D}=1.4809$. Each successive fraction had an increasing refractive index except the fourth, which was considerably lower, having $n\frac{20°}{D}=1.4647$, $\alpha\frac{20°}{D}=11.79°$. After this fourth fraction of 21 grams had remained a number of days in the ice box a white crystalline precipitate weighing 0.4 gram settled out. Recrystallized several times from dilute alcohol, this crystalline precipitate melted at 58–59°. It had a bitter taste, but it had no odor, and it had too high a melting point to be camphene. Burgess and Child *(1)* have reported finding *l*-camphene in Italian lemon oil. After remaining in a sulphuric acid desiccator for five days, it melted at 64° to 65°. It was set aside again in the desiccator, and after five days the crystals had largely liquefied. These results indicate that this is the same as the substance first reported by Romeo in 1925 (*17*). It is apparently an aldehyde, as it gave a positive test with fuchsine aldehyde reagent, and reduced ammoniacal silver nitrate solution. It was more soluble in hot water than in cold water, being only slightly soluble in the latter. It gave no color with ferric chloride, but it produced a red color with concentrated sulphuric acid, and an aqueous solution decolorized potassium permanganate and aqueous bromine. Romeo reported that the anhydrous form had the composition $C_{10}H_{18}O_2$.

The liquid part of the fraction containing this solid aldehyde was tested for camphene by the isoborneol test, but no crystals appeared. Not enough of the first fractions was available from this or a later lot of lemon oil to carry out the camphene test as described by Burgess and Child.

As no deposit appeared in the other four fractions they were set aside and combined with corresponding fractions from lot 2 of lemon oil.

STEAM DISTILLATION OF THE RESIDUE

After the distillation at 120° C. and 3 millimeters the 402 grams of residue, called residue 1, was distilled with steam at ordinary pressure. Four fractions were separated. (Table 8.) As these showed no marked variation in optical rotation or refractive index, they were

combined and later mixed with a corresponding fraction from another lot of lemon oil.

TABLE 8.—*Fractions obtained from lot 1 of lemon oil by steam distillation of the residue after distillation at 120° C. and 3 millimeters*

Fraction	Quantity obtained	Time distilled	Optical rotation	Refractive index
	Grams	*Hours*	°	
1	110	6	−12.48	1.4799
2	45	3	−14.56	1.4804
3	46	6	−17.20	1.4809
4	19	6	−20.53	1.4834

DISTILLATION OF LOT 2

The remainder of the lemon-oil samples, Nos. 27 to 73, inclusive, were combined and called lot 2. This lot weighed 13,816 grams, and had the following physical constants and composition: $d\frac{25°C.}{25°C.}=0.8503$; $\alpha\frac{20°}{D}=62.28°$, for the 10 per cent distillate, 57.70°; $n\frac{20°}{D}=1.4743$, for the 10 per cent distillate, 1.4728; citral (Kleber), 2.8 per cent, (Hiltner) 2.3 per cent; residue, 2.87 per cent. This lot was distilled in 1,600-gram batches at 10 millimeters.

IDENTIFICATION OF β-PINENE IN THE FIRST FRACTION

The first fraction, $n\frac{20°}{D}=1.4735$, consisting of 5 per cent of lot 2, weighing 650 grams, was redistilled several times at 10 millimeters. The Young column and finally a Claisen flask were used. Four fractions with a total weight of 274 grams were separated (Table 9), and the residue, consisting of limonene, was discarded.

TABLE 9.—*Fractions obtained from the first 5 per cent fraction of lot 2 of lemon oil*

Fraction	Boiling point at 10 mm.	Weight	Optical rotation	Refractive index	Specific gravity
	°C.	*Grams*	°		
1	47–52	24	9.57	1.4719	0.8625
2	52–54	43	16.23	1.4725	.8575
3	54–56	102	29.24	1.4730	----------
4	56–58	105	59.33	1.4736	----------

These fractions were kept in the ice box for several days and treated separately with 40 per cent sodium bisulphite. The small quantities of bisulphite compound formed were combined. Only a few drops of aldehyde were regenerated with sodium carbonate. It gave a positive test with fuchsine aldehyde reagent and had an odor resembling octylic and nonylic aldehyde, but it had no resemblance to citral or methyl heptenone. The refractive index was $n\frac{20°}{D}=1.4359$.

Fraction 1, aldehyde free, was then redistilled at 10 millimeters. (Table 10.)

TABLE 10.—*Fractions obtained from fraction 1, aldehyde-free lemon oil, shown in Table 9*

Fraction	Temperature	Weight	Optical rotation	Refractive index
	°C.	Grams	°	
1a	47–48	3	−5.83	1.4710
1b	48	3	−2.77	1.4712
1c	48–49	6	+2.08	1.4718
1d[1]	----------	--------	+13.87	1.4736

[1] Residue in flask.

The nitrosochloride crystals obtained from 1a melted at 103° to 104° C., and were all α-pinene except for a trace of limonene and a few cube-shaped crystals. Pure pinene nitrosochloride melts at 103°. The nitrosochloride crystals from 1b melted at 102° to 103° and were about four-fifths pinene and one-fifth cubes with a trace of limonene. The nitrosochloride crystals from 1c were all α-pinene except for a trace of limonene, whereas 1d yielded about half pinene and half limonene. No cubes were obtained from either 1c or 1d.

As β-phellandrene has been reported in lemon oil (*6, v. 3, p. 25*), it was thought that possibly the cubes were β-phellandrene nitrosochloride crystals. α-Phellandrene does not yield a crystalline nitrosochloride. Attempts to obtain a known sample of β-phellandrene for comparison were unsuccessful, and as none of 1a or 1b remained, it was impossible to carry out the crystalline nitrosite compound test (*8, p. 109*).

When 10 grams of 1d was oxidized according to Wallach's *(6, v. 1, p. 299)* directions, crystals of nopinic acid which melted at 125° to 126° were obtained, proving that lemon oil contains β-pinene.

FORMATION OF THE TETRABROMIDE FROM THE *d*-LIMONENE

After the first 5 per cent fraction, the limonene fraction, $n\frac{20°}{D}=1.4734$, was collected at 57° to 58°. Crystals of limonene tetrabromide melting at 103° to 104° were produced by treating part of this fraction of the oil in glacial acetic acid solution with bromine.

OCTYLIC AND NONYLIC ALDEHYDES

As methyl heptenone, which has been reported in lemon oil (*19, p. 39*) and which boils at 173° to 174°C., would have passed over with the limonene fraction during the vacuum distillation, 6 liters of this fraction was treated in the ice box for four days with 40 per cent sodium bisulphite. When the crystals obtained were treated with sodium carbonate solution and distilled, 2.9 grams of oil was obtained. It gave a positive test with the fuchsine aldehyde reagent, and had the constants $d\frac{25°}{25°}=0.8333$, $\alpha\frac{20°}{D}=+1.39°$, $n\frac{20°}{D}=1.4252$. The odor resembled that of octylic and nonylic aldehyde, but it did not resemble the odor of methyl heptenone, citral, or citronellal. This is probably the same as the few drops of aldehyde obtained from the first 5 per cent distillate. The refractive index of octylic aldehyde is 1.4196; that of nonylic is 1.4245. The semicarbazone melted at

91° C. and the naphthocinchoninic acid at 238° to 239° (corrected). Burgess (*4*) first reported a similar aldehyde, which Von Soden and Rojahn (*21*) showed consists of two aldehydes, octylic and nonylic, the latter predominating. The results obtained here show that both octylic and nonylic aldehydes are in lemon oil.

ISOLATION OF CITRAL

After the limonene was distilled off, the residue (residue 1), 1,221 grams, was steam distilled. Two main fractions separated (Table 11). Fraction 2 was combined with the corresponding fraction obtained from lot 1.

TABLE 11.—*Fractions obtained from lot 2 of lemon oil by steam distillation of the residue*

Fraction	Weight	Optical rotation	Refractive index
	Grams		
1	432	+8.88	1.4775
2	684	−13.87	1.4804

After the fractions were shaken with equal volumes of ether and 40 per cent sodium bisulphite and the bisulphite compound was decomposed with sodium carbonate, 30 grams of aldehyde was obtained from fraction 1 and 35 grams from fraction 2. It had an odor of citral. The constants were: $\alpha\frac{20°}{D}=0.0°$, $n\frac{20°}{D}=1.4855$. The aldehyde from the two fractions, a total of 65 grams, was combined and distilled at 10 millimeters. The results are given in Table 12. A few grams of dark substance remained in the flask.

TABLE 12.—*Fractions obtained by distillation of aldehydes removed from residue of lot 2 of lemon oil by steam distillation*

Fraction	Boiling point at 10 mm.	Weight	Optical rotation	Refractive index	Specific gravity
	°*C.*	*Grams*	°		
1	100–105	18	0.0	1.4848	
2	105–106	43	.0	1.4878	0.8903

Schimmel & Co. (*6, v. 1, p. 409*) report the following constants on carefully purified citral from Italian lemon oil: $\alpha\frac{20°}{D}=0.0°$, $n\frac{20°}{D}=1.4885$, $d\ 15°=0.8926$.

A 2-gram portion of fraction 2 (Table 12) in absolute alcohol was heated three hours on the steam bath with 2 grams pyruvic acid and 2 grams β-naphthylamine, then cooled and filtered. Crystals of α-citryl β-naphthocinchoninic acid were recrystallized three times. The melting point was 199° to 200° C. (corrected). When they were recrystallized again the melting point was 199° to 200° (corrected).

The semicarbazone was prepared from 1 cubic centimeter of fraction 2 and 1 gram semicarbazid hydrochloride with 1 gram

sodium acetate. After recrystallizing three times from alcohol, the crystals melted at 134° to 135°. The fact that the melting point of the recrystallized crystals was 134° to 135° showed the crystals to be a mixture of α- and β-citral semicarbazones. When the mixture was treated with ether, according to Parry (*14, p. 186*), crystals of α-citral semicarbazone were obtained which melted at 163° to 164°.

No indication of citronellal was given by odor or tests.

IDENTIFICATION OF ACETIC AND OILY ACIDS

After the citral was removed from the fractions obtained by steam-distilling residue 1 of lots 1 and 2, the combined aldehyde-free oil amounted to 677 grams. The constants were $\alpha\frac{20°}{D}=-10.40°$, $n\frac{20°}{D}=1.4769$. Ten grams was acetylated and 2 grams of the acetyl compound was saponified. The ester value obtained was 127.4, equivalent to 38.7 per cent of the alcohol $C_{10}H_{18}O$. Then 222 grams was saponified with alcoholic potassium hydroxide. After the oily portion was removed with ether, the aqueous layer was steam distilled to remove any oil, then acidified with sulphuric acid and distilled. After removal of the thin layer of oily acid with ether, 33.3 cubic centimeters half normal sodium hydroxide was required to neutralize the aqueous distillate. Then tests for formic acid were made on the neutralized distillate. It did not reduce permanganate solution or yield a precipitate with mercuric chloride, and no mirror or precipitate appeared when the distillate was warmed with silver nitrate solution, showing that it did not contain formic acid.

Upon evaporation to dryness, 1.09 grams of a white salt was obtained. On the assumption that this was sodium acetate, the test of Reid (*16*) was carried out to form the p-nitro benzyl acetate with p-nitro benzyl bromide. The crystals melted at 77° to 78° C. An ester prepared from sodium acetate melted at 77° to 78°, and a mixture of the two showed no depression of the melting point. Therefore acetic acid was present.

The remainder of the aldehyde-free oil was saponified, and a total of 2.3 grams of oily acid obtained. The constants were: $n\frac{20°}{D}=1.4523$, $d\frac{25°}{25°}=0.9222$. The boiling point was approximately 240° to 245° C. After the acid was neutralized with sodium hydroxide, three determinations of the silver salt were made. (Table 13.)

TABLE 13.—*Silver salts of oily acids in aldehyde-free lemon oil*

Lot	Crop of crystals	Weight of silver salts	Weight of silver	Percentage[1] of silver
		Grams	*Grams*	
1	First	0.0527	0.0204	38.7
1	Second	.0476	.0192	40.3
2	Total	.1195	.0467	39.1
3	do	.1243	.0492	39.6

[1] Silver salt of capric acid ($AgC_{10}H_{19}O_2$) contains 38.7 per cent silver; silver salt of caprylic acid ($AgC_8H_{15}O_2$) contains 43 per cent silver.

These results and the fact that an odor of a high aliphatic acid developed upon ignition indicate that the oily acid is a mixture of caprylic and capric acids, the latter predominating.

ISOLATION OF GERANIOL

The oil remaining after saponification of the aldehyde-free fractions 1 and 2 was treated with 35 grams of powdered phthalic anhydride and refluxed on the steam bath for one hour. After it had cooled, 26 grams of sodium carbonate in solution was added, and the oil not esterified by the phthalic anhydride was removed with ether. The primary alcohol ester was then saponified with 20 grams of sodium hydroxide by refluxing for half an hour. After this had been steam distilled, 6.2 grams of primary alcohol having an odor of geraniol was obtained. The constants were: $d\frac{25°}{25°}=0.8769$, $n\frac{20°}{D}=1.4736$, $\alpha\frac{20°}{D}=0.0°$. This was distilled at 10 millimeters pressure. (Table 14.)

TABLE 14.—*Fractions obtained from lemon oil by distillation of primary alcohol*

Fraction	Weight	Boiling point at 10 mm.	Refractive index	Specific gravity	Optical rotation
	Grams	°*C.*			°
1	2	105–109	1.4733	----------	0.0
2	4	109–110	1.4746	0.8801	.0

One gram of fraction 2 (Table 14) gave a strong odor of citral when oxidized with chromic acid. The oil removed by steam distillation yielded a precipitate in sodium bisulphite solution, indicating that an aldehyde had been formed from an alcohol in fraction 2.

The diphenylurethane of the compound was formed according to the method of Erdmann and Huth (*6, v. 1, p. 361*) by heating 1 gram of fraction 2 with 1.5 grams of diphenyl carbamine chloride and 1.35 grams pyridine for two hours in a water bath. After it had been steam distilled the first crystals obtained melted at 77° C. After they had been recrystallized from alcohol several times the melting point reached 81° to 82°. A diphenylurethane prepared from geraniol obtained from Fritzsche Bros. melted at 81° to 82°, and a mixture of the two melted at the same temperature. Therefore the primary alcohol in the lemon oil is geraniol.

EXAMINATION FOR TERTIARY ALCOHOLS AND IDENTIFICATION OF γ-TERPINENE

The oil (420 grams) not esterified by the phthalic anhydride was dried over anhydrous sodium sulphate and distilled with a Hempel fractionating column at 10 millimeters into four fractions. These fractions were redistilled twice in Claisen flasks at 10 millimeters, and the fractions given in Table 15 were obtained.

TABLE 15.—*Fractions obtained from lemon oil not esterified by phthalic anhydride*

Fraction	Boiling point at 10 mm.	Weight	Optical rotation	Refractive index	Specific gravity
	°C.	Grams	°		
1	56–61	14	+56.17	1.4762	
2	61–64	13	+54.79	1.4769	
3	64–66	20	+48.68	1.4767	0.8487
4	66–87	5	24.41	1.4747	.8598
5	87–100	5	0.0	1.4750	.8809
6	100–105	19	−8.32	1.4784	.8848
7	105–110	91	−11.93	1.4803	.8823
8	110–116	75	−14.98	1.4824	.8809
9	116–126	56	−26.63	1.4875	.8818
10	126–134	58	−38.42	1.4912	.8792
11	134–142	6	−42.30	1.4920	.8836
[1]					

[1] 30 grams of dark oil remained in the flask.

Fractions 4, 5, 6, 7, and 8 were again distilled in order to separate fractions at approximately the boiling points of linalool and terpineol, which have been reported as present in Italian lemon oils (*6, v. 3, p. 27*). Table 16 shows the results obtained on these fractions.

TABLE 16.—*Redistillation of fractions 4, 5, 6, 7, and 8 of lemon oil shown in Table 15*

Fraction	Boiling point at 10 mm.	Subfraction	Weight	Optical rotation	Refractive index	Specific gravity
	°C.		Grams	°		
4	[1] 66–70	4a	2.5	+26.63	1.4744	0.8491
	70–85					
	[2]					
5	[1] 80–88	5a	4	−4.16	1.4746	.8855
	88–104					
	[3]					
6	90–98	6a	4	0.0	1.4762	.8806
	98–109	6b	11	−11.09	1.4782	.8844
	[4]					
7	101–105	7a	10	−6.24	1.4788	.8818
	105–107	7b	44	−10.82	1.4793	.8834
	107–108	7c	17	−11.51	1.4800	.8822
	108–110	[5] 7d	8	−12.48	1.4804	
	[6]					
		$7d_1$				.8814
8	109–110	[5] 8a	51	−12.48	1.4810	
	110–115	8b	12	−17.06	1.4831	.8817
	115–120	8c	5	−23.58	1.4860	
	[7]	8d	6	−36.06	1.4923	

[1] Discarded.
[2] About 1 gram left. Was added to fraction 5.
[3] About 0.5 gram left. Was added to fraction 6.
[4] 4 grams left. Was added to fraction 7.
[5] After the refractive index determination 7d and 8a were combined and designated as $7d_1$.
[6] 12 grams left. Was added to fraction 8.
[7] Left in flask.

All the fractions in Table 16 except 4a liberated hydrogen in the metallic sodium test, showing that they contained an alcohol. Fraction 8*d* gave only a slight test.

Attempts to form phenylurethanes with phenylisocyanate on fractions 4a, 5a, 6b, 7b, and $7d_1$ were unsuccessful, although no difficulty was encountered in forming them on known samples of linalool and terpineol. Even when $7d_1$ was allowed to remain for two weeks with the phenylisocyanate, it did not yield crystals of phenylurethane. Likewise crystals of terpin hydrate did not form when 4a, 5a, 7c, and $7d_1$ were allowed to stand with 5 per cent sulphuric acid for 10 days, being shaken several times a day.

Crystals of the dihydrochloride of terpineol could not be produced on $7d_1$ according to the method of Wallach (*24*), although a sample of terpineol yielded crystals melting at 49°. Crystals were not obtained upon passing dry hydrochloric acid gas into a cold ether solution of $7d_1$ or upon carrying out the nitrosochloride test as given by terpineol.

Elementary analysis of 6b and 7a combined gave the following results:

For $C_{10}H_{18}O$:
Calculated..... C, 77.86 per cent; H, 11.77 per cent.
Found I..... C, 77.58 per cent; H, 11.80 per cent.
Found II..... C, 77.43 per cent; H, 11.85 per cent.

These results show the presence of an alcohol, $C_{10}H_{18}O$, which, however, has not yielded to the tests for linalool and terpineol. The phthalic anhydride had removed the geraniol, as was shown by the fact that tests for geraniol on these fractions were negative. That the oil contains a trace of linalool was indicated by the following test. Two grams of 6a was oxidized in the cold with chromic acid mixture. After this had been made alkaline with sodium carbonate, and distilled, and the distilled oil had been treated with 40 per cent sodium bisulphite in the ice box, crystals were obtained. When these were decomposed with sodium carbonate a few drops of oil having a strong odor of citral distilled over.

The presence of γ–terpinene was established by oxidizing 45 grams of a mixture of fractions 1, 2, and 3 (Table 15) with permanganate according to Wallach (*6, v. 1, p. 321*) and forming the erythritol $C_{10}H_{16}(OH)_4$, which melted at 238–239° (corrected). The quantity of γ–terpinene in the lemon oil was no doubt small, as only 0.1 gram of erythritol crystals was obtained after a period of five weeks. At ordinary pressure, these fractions boiled at about 175°–185°, the range in which γ–terpinene boils.

In order to see whether more distinctive fractions could be obtained, fractions 6b to $7d_1$, inclusive, were combined and distilled at atmospheric pressure. Although 10 fractions were separated, their physical constants were similar to those given in Table 16.

IDENTIFICATION OF THE SESQUITERPENES BISABOLENE AND CADINENE

The higher boiling fractions 10 and 11 (Table 15) were examined for sesquiterpenes. The physical constants resembled those given for bisabolene, formerly called limene. Upon passing dry gaseous hydrogen chloride into an ice-cold ether solution of these fractions, crystals of bisabolene trichlorhydrate were obtained, which, after recrystallizing from hot alcohol, melted at 79° to 80° C. Upon addition of hydrochloric acid gas to the ether solution of fraction 10, it turned red, then purple. Fraction 11 turned a red which increased in intensity. The crystals were optically inactive in chloroform solution.

As the sesquiterpene cadinene boils at a higher temperature than bisabolene, part of the 30 grams of substance remaining in the flask after fraction 11 was distilled off was treated with dry hydrochloric acid gas in ether solution. The crystals obtained were bisabolene trichlorhydrate, melting at 79° to 80° C. Cadinene dichlorhydrate

melts at 117°. A positive test for cadinene was obtained by dissolving a portion of fraction 10 in chloroform and shaking it with a few drops of concentrated sulphuric acid according to the directions of Heusler (*8, p. 415*). It became green, then blue, and when it was warmed the color deepened, and a slight red appeared. Fraction 11 gave deeper shades of these colors. As bisabolene does not yield a solid nitrosochloride or nitrosate, attempts were made to form these cadinene compounds on fractions 10 and 11, and also on the residue, according to Heusler's method. Only the residue yielded a precipitate, very slight, of nitrosochloride, which melted at 63°. Not enough was available to recrystallize and purify. Cadinene nitrosochloride melts at 93° to 94°.

In the nitrosate test, yellow precipitates were obtained on all fractions, but efforts to form crystals by dissolving the precipitates in several solvents were unsuccessful. The precipitate, which melted at 72° C. to an opaque liquid, was finally raised to 76° to 77° by dissolving it several times in ether. Cadinene nitrosate melts and decomposes at 105° to 110°.

Evidently the higher boiling portion of the lemon oil is largely bisabolene, with probably a trace of cadinene.

SEPARATION OF AN AMORPHOUS COMPOUND FROM THE RESIDUE

The pastelike substance (residue 2) remaining after steam distillation of residue 1 was soluble in hot 95 per cent alcohol, hot benzene, and carbon tetrachloride. A small quantity remained undissolved when treated with ether, ethyl acetate, and petroleum ether. After 40 grams was exhausted with ether, there remained 1.38 grams of white powder, which was not very soluble in methyl or ethyl alcohol, ethyl acetate, or chloroform. It dissolved in hot benzene, carbon tetrachloride, and acetone. Numerous efforts to produce crystals were unsuccessful, the substance always appearing in the amorphous state. Even when the solutions were warmed with charcoal and filtered they did not yield crystals upon standing. It had a definite melting point of 71° to 72°. All the tests of Mulliken (*11*) made to establish the identity of the compound gave negative results. The bromine test for unsaturation was also negative. The fact that concentrated sulphuric acid had no effect on it indicated the presence of a paraffin hydrocarbon.

This substance is different from citroptene, which was found in Italian lemon oil by Schmidt (*20*) and has a melting point of 146°. Theulier (*23*) mentions an amorphous compound melting at 76° which he separated from the nonvolatile residue and which may have been the same as this substance.

Only a few drops of fatty acid were obtained upon saponifying 50 grams of residue 2.

ORANGE OIL

DISTILLATION OF THE OIL

In determining the composition of the orange oil, the samples of Washington Navel and Valencia oils were combined, and each kind was distilled separately. As the results, however, were similar, they will be taken up as a whole, and the few differences noted. Table 17 contains the results of analyses of the combined lots of oils.

TABLE 17.—*Analyses of composite lots of orange oils*

Lot No.	Type	Weight	Specific gravity	Optical rotation		Refractive index		Residue	Citral		Esters
				Original	10 per cent distillate	Original	10 per cent distillate		Kleber	Hiltner	
		Grams		°	°			*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Washington Navel	10,890	0.8426	98.20	98.48	1.4733	1.4723	2.18	1.1	0.20	0.78
2	do	5,490	.8450	97.23	98.34	1.4736	1.4724	6.35	.9	.18	
3	Valencia	5,024	.8445	97.52		1.4735		4.55	1.3	.24	
4	do	3,390	.8432	97.52		1.4731		4.76	1.7	.29	1.06
5	do	9,530	.8443	98.48	98.89	1.4736	1.4723	3.54	1.4	.19	.70

A general outline of the method used for the identification of the constituents of the orange oils is shown diagrammatically in Figure 3.

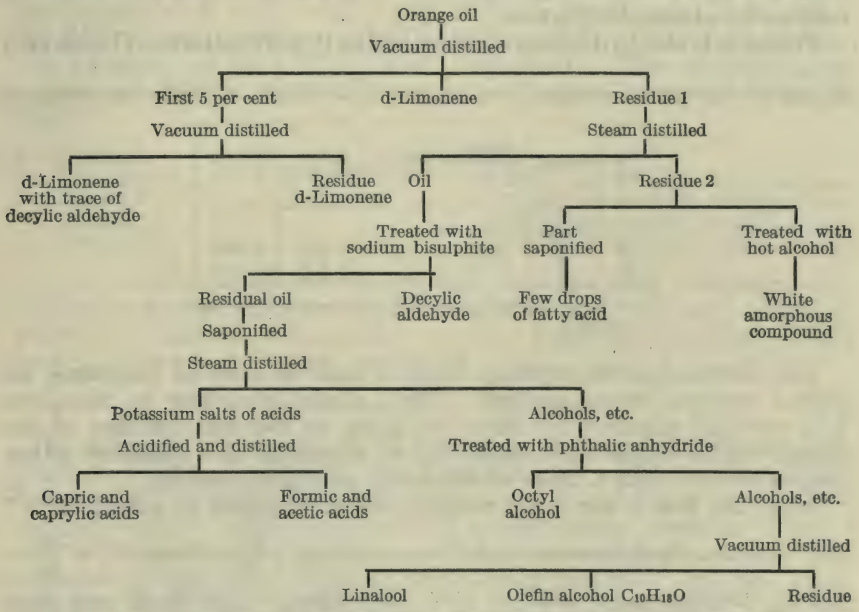

FIGURE 3.—General outline of method used for identification of constituents of orange oils

The following summary of the distillation of lot 1 at 12 millimeters pressure will illustrate the various fractions obtained when the oils were distilled.

The first 5 per cent distilled at 59° to 62° C. The temperature of the water bath in which the flask rested was 75° to 80°. Upon redistilling, two fractions were separated. (Table 18.)

TABLE 18.—*Fractions obtained from the first 5 per cent fraction of orange oil*

Fraction	Weight	Optical rotation	Refractive index
	Grams	°	
1	169	89.94	1.4716
2	76	92.47	1.4719
(1)	305	98.89	1.4732

[1] Left in flask. The boiling point was 175° (760 mm.).

From fraction 1 a small quantity of aldehyde (0.2 6 gram)was isolated with sodium bisulphite. The odor resembled that of decylic. The constants were: $d\frac{25°}{25°}=0.8597$, $n\frac{20°}{D}=1.4276$. From 0.15 gram of the aldehyde a small quantity of semicarbazone crystals was obtained, which melted at 49° to 50° C. From this fraction of the Valencia oil, a few drops of aldehyde, $n\frac{20°}{D}=1.4350$, yielded a semicarbazone melting at 68° to 69° C. The small quantities of aldehyde available were not satisfactory for the semicarbazide-hydrochloride test. It is no doubt a part of the decylic aldehyde, some of which distilled over with the first fraction and some of which was later isolated from the residue by steam distillation.

Fraction 1, aldehyde-free, was distilled at 10 millimeters. (Table 19.)

TABLE 19.—*Fractions obtained from fraction 1 (Table 18), aldehyde-free orange oil*

Fraction	Weight	Boiling point at 10 mm.	Optical rotation	Refractive index	Specific gravity
	Grams	° *C.*	°		
1a	20	50–54	78. 5	1. 4704	0. 8471
1b	10	54–56	85. 9	1. 4713	----------
(1)	----------	----------	92. 5	1. 4725	----------

[1] Residue.

The nitrosochloride crystals from 1a and 1b were all limonene, no pinene crystals being present. Tests made according to Mulliken (*11*) were all negative on these fractions, so the first fraction of the orange oil is apparently made up of limonene and possibly other hydrocarbons, with a trace of aldehyde, probably decylic.

After the first 5 per cent, most of the oil distilled at about 62° C. and was mainly limonene with the constants $\alpha\frac{20°}{D}=100.97°$; $n\frac{20°}{D}=1.4728$, boiling point 175° to 176° (760 mm.). The flask was then placed in a calcium chloride bath, which was gradually raised to 110°. A total of 211 grams, called fraction 3, distilled. The constants of this fraction were $\alpha\frac{20°}{D}=100.27°$; $n\frac{20°}{D}=1.4731$, boiling point 176° to 177° (760 mm.). It was largely limonene. When the limonene fractions were treated in glacial acetic acid with bromine, the tetrabromide was formed. The melting point was 103° to 104°.

While the temperature of the bath remained at 110°, the pressure was reduced to 7 millimeters. Fraction 4, consisting of 15 grams, was then obtained. The constants were $\alpha\frac{20°}{D}=69.77°$, $n\frac{20°}{D}=1.4716$.

As with the lemon oil, it was necessary to steam-distill the residue (residue 1) in order to recover the oxygenated constituents of the

orange oil. Fraction 5, 56 grams, resulted. The constants were $\alpha\frac{20°}{D}=35.23°$, $n\frac{20°}{D}=1.4736$.

ISOLATION OF DECYLIC ALDEHYDE

Fractions 4 and 5 were combined. The aldehyde was removed with sodium bisulphite. It had the following constants: Boiling point, 205° to 207° C. (corrected) at 756 mm., $d\frac{25°}{25°}=0.8352$, $n\frac{20°}{D}=1.4296$, $\alpha\frac{20°}{D}=0.0°$. The aldehyde from the Valencia oils had the constants: $d\frac{25°}{25°}=0.8256$, $n\frac{20°}{D}=1.4283$, $\alpha\frac{20°}{D}=0.0°$. The naphthocinchoninic acid, made with β-naphthylamine and pyruvic acid, from the Washington Navel oil melted at 242° to 243° (corrected) and from the Valencia oil at 238° to 239° (corrected). The semicarbazone melted at 101° to 102°. Elementary analysis gave the following results:

For $C_{10}H_{20}O$:

Calculated	C, 76.9 per cent; H, 12.8 per cent.
Found I	C, 76.58 per cent; H, 13.09 per cent.
Found II	C, 76.38 per cent; H, 13.09 per cent.
Found II	C, 76.67 per cent; H, 12.98 per cent.

These results, together with the fact that the odor compared with that of a known decylic sample, indicate that the only aldehyde present in California orange oil is decylic. Stephan (*22*) reported only decylic aldehyde in Italian orange oil.

EXAMINATION OF OILY ACID

Ten grams of the combined aldehyde-free fractions 4 and 5 was acetylated, and 0.78 gram of the acetyl compound was saponified. The ester value obtained was 50.3, equivalent to 14.4 per cent of the alcohol $C_{10}H_{18}O$. The remainder of aldehyde-free fractions 4 and 5 was then saponified, and the oil was removed with ether. The aqueous portion was acidified and steam distilled, and the small quantity of oily acid removed from the distillate with ether was converted to its silver salts. The results are shown in Table 20.

TABLE 20.—*Silver salts of oily acids in aldehyde-free orange oil*

Lot	Crop of crystals	Weight of silver salts	Weight of silver	Percentage of silver [1]
		Gram	*Gram*	*Per cent*
1	Total	0.0902	0.0368	40.8
2a	First	.0503	.0195	38.8
	Second	.0466	.0191	41.0
2b	First	.0579	.0227	39.2
	Second	.0494	.0200	40.5
2c	Total	.0819	.0333	40.6
3, 4 and 5, combined, a	do	.0553	.0217	39.2
3, 4, and 5, combined, b	do	.0472	.0184	39.0

[1] Silver salt of caprylic acid ($AgC_8H_{15}O_2$) contains 43 per cent silver; silver salt of capric acid ($AgC_{10}H_{19}O_2$) contains 38.7 per cent silver.

Apparently the oily acid consists of caprylic and capric acids, the latter predominating.

IDENTIFICATION OF FORMIC AND ACETIC ACIDS

After removal of the oily acid, the aqueous distillate was neutralized with sodium hydroxide, and the following positive tests for formic acid were obtained: It reduced permanganate solution and formed a precipitate of mercurous chloride when heated with mercuric chloride. It formed a precipitate and mirror when warmed with silver nitrate.

The formic acid was removed with potassium permanganate, and the filtrate evaporated to dryness. The residue was then identified as sodium acetate by converting it to p-nitro benzyl acetate with p-nitrol benzyl bromide according to the method of Reid (*16*). It melted at 77° to 78° C., and when it was mixed with the ester prepared from pure sodium acetate, the melting point did not change.

IDENTIFICATION OF A PRIMARY ALCOHOL

The oil remaining after saponification of the aldehyde-free fractions 4 and 5 was treated with powdered phthalic anhydride to remove the small quantity of primary alcohol. The Washington Navel oil yielded 0.5 cubic centimeter of a compound having the constants $d\frac{25°}{25°}=0.8801$ and $n\frac{20°}{D}=1.4663$. The Valencia oil yielded the same quantity. The constants were $d\frac{25°}{25°}=0.8506$ and $n\frac{20°}{D}=1.4493$. Because of the small quantities these compounds are no doubt impure.

When the acids obtained by oxidation with Beckman's chromic acid mixture were transformed into their silver salts, the silver content was 43, 43.5, and 44 per cent. The average was 43.5. The silver salt of caprylic acid from octyl alcohol contains 43 per cent silver; the silver salt of pelargonic acid from nonyl alcohol contains 40.8 per cent silver. These results indicate that a small quantity of octyl alcohol is in orange oil.

EXAMINATION OF TERTIARY ALCOHOLS

The oil remaining after the treatment with phthalic anhydride was fractionated several times at 10 millimeters. Table 21 shows the fractions obtained from 69 cubic centimeters of the total 83 cubic centimeters of the combined Washington Navel oils. After fraction 5 was obtained the temperature of the oil bath was slowly raised to about 150° C. During this time the distillation gradually decreased until the thermometer failed to register the upper limit of the boiling point of fraction 6.

TABLE 21.—*Fractions obtained from the Washington Navel orange oil after treatment with phthalic anhydride*

Fraction	Boiling point at 10 mm.	Volume	Refractive index	Optical rotation	Specific gravity
	°C.	c. c.		°	
1	63– 82	20	1.4740	92.51	----------
2	82– 84	1.3	1.4764	47.16	----------
3	84– 88	1.6	1.4738	26.63	----------
4	88–102	5.5	1.4830	24.41	----------
5	102–107	7.5	1.4888	22.75	0.9194
6	107–up	21	1.5024	57.42	----------

The metallic sodium test for alcohol was positive on all fractions except No. 6. Fraction 3 was examined especially for linalool and fraction 5 for terpineol, but attempts to form the phenylurethane, nitrosochloride, and terpin hydrate gave negative results.

Table 22 shows the fractions obtained from the Valencia oil. The metallic sodium test for alcohols was positive on all fractions except No. 6. Fraction 3 was examined for linalool and fraction 5 for terpineol, but as with the Washington Navel oil, attempts to form the phenylurethane, nitrosochloride and terpin hydrate were unsuccessful. Upon oxidizing 1.5 cubic centimeters of fraction 3 in the cold, however, and treating the distillate with sodium bisulphite, a small quantity of precipitate was obtained which yielded a drop of oil with an odor of citral, indicating that it contained a trace of linalool.

TABLE 22.—*Fractions obtained from the Valencia orange oil after treatment with phthalic anhydride*

Fraction	Boiling point at 10 mm.	Refractive index	Optical rotation	Specific gravity
	° C.		°	
1	63– 80	1.4693	62.83	----------
2	80– 84	----------	33.42	----------
3	84– 88	1.4645	23.85	0.8712
4	88–102	----------	27.05	----------
5	102–107	1.4804	28.43	.9005
6	107–up	1.4996	54.37	----------

Elementary analysis of fraction 3 gave the following results:

For $C_{10}H_{18}O$:

Calculated----------C, 77.86 per cent; H, 11.77 per cent.
Found I----------C, 76.93 per cent; H, 11.88 per cent.
Found II----------C, 77.16 per cent; H, 11.99 per cent.

The results obtained on fraction 3, together with its physical constants, show that it is practically the same as the olefin alcohol $C_{10}H_{18}O$ that Hall and Wilson (7) found in the volatile constituents of Valencia orange juice. They state that it seems quite probable that the substance is closely related to linalool, but not identical with

it. At the suggestion of Mr. Hall the fraction was allowed to remain four months in a sealed tube in the ice box. A phenylurethane melting at 60° to 61° C. was then obtained. Crystals resulted only after the pasty mass was dissolved in a 50 per cent alcoholic solution of ethylene glycol.

Fractions 6 (Tables 21 and 22) were refractionated, but crystals were not obtained on attempting to form a nitrosate, nitrosochloride, or chlorhydrate, as tests for sesquiterpenes.

SEPARATION OF AN AMORPHOUS COMPOUND FROM THE RESIDUE

The pastelike substance (residue 2) remaining after steam distillation of residue 1 was nearly all soluble in cold alcohol, cold petroleum ether, benzene, and ethyl acetate. After 40 grams of it was treated with ether, 0.65 gram of brown solid remained, which would not dissolve in carbon tetrachloride, chloroform, and several other solvents, and would not melt when heated to 260° C. A similar substance remained after residue 2 was treated with hot alcohol. Upon cooling, the hot alcohol deposited 0.2 gram of a white amorphous compound, which melted at 62° to 63°, but did not yield to crystallization. Tests to establish its identity gave negative results. The compound appears to be similar to that found in the lemon residue.

Only a few drops of fatty acid was obtained upon saponifying 50 grams of residue 2.

SUMMARY

The bulletin contains the results of analyses of commercial California machine-made lemon and orange oils, and the chemical composition of the oils.

Seventy-three samples of lemon oil, 63 of Valencia orange oil, and 31 of Washington Navel orange oil, all obtained from commercial by-products plants, were analyzed over a period of four years. Summaries of the results have been compared with those of Italian hand-made oils, and also with those of California oils made by the sponge method, and in a laboratory machine.

The effect of temperature, air, and light on lemon and orange oils over a storage period of 20 months was determined.

Besides the d-limonene, which comprises about 90 per cent or more of the oil, the following constituents were found in commercial California lemon oil: α-and β-pinene, citral, octylic and nonylic aldehydes, acetic, capric, and caprylic acids, geraniol, γ-terpinene, and the sesquiterpene bisabolene. The following substances were not completely identified: A solid aldehyde melting at 58° to 59° C., a tertiary alcohol $C_{10}H_{18}O$, and a white amorphous compound melting at 71° to 72° C. Traces of linalool and cadinene were found.

The substances identified in commercial California Washington Navel and Valencia orange oils were practically the same. Besides the d-limonene, which comprises 90 per cent or more of the oil, the following constituents were found: Decylic aldehyde; formic, acetic, capric, and caprylic acids; octyl alcohol; an olefin alcohol, $C_{10}H_{18}O$, closely related to linalool; and an unidentified white amorphous compound melting at 62° to 63°. It was indicated that the oils contain a trace of linalool.

LITERATURE CITED

(1) ANONYMOUS.
1903. LAEVO CAMPHENE, A NEW CONSTITUENT OF LEMON OIL. Chem. and Drug. 62: 476–477.

(2) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.
1925. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. COMPILED BY THE COMMITTEE ON EDITING METHODS OF ANALYSIS. REVISED TO JULY 1, 1924. Ed. 2, 535 p., illus. Washington, D. C.

(3) ———
1929. CHANGES IN THE OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . FLAVORING EXTRACTS. Jour. Assoc. Off. Agr. Chem. 12: 48–49.

(4) BURGESS, H. E.
1901. TWO NEW SUBSTANCES IN LEMON OIL. Chem. Soc. [London] Proc. 17: 171–172.

(5) CHACE, E. M.
1919. THE OCCURRENCE OF PINENE IN LEMON OIL. U. S. Dept. Agr., Bur. Chem. Circ. 46, 24 p., illus.

(6) GILDEMEISTER, E., and HOFFMANN, F.
1913–22. THE VOLATILE OILS. (Ed. 2 by E. Gildemeister. Translated by E. Kremers). Ed. 2, 3 v., illus. London, Bombay, [etc.]

(7) HALL J. A., and WILSON, C. P.
1925. THE VOLATILE CONSTITUENTS OF VALENCIA ORANGE JUICE. Jour. Amer. Chem. Soc. 47: 2575–2584.

(8) HEUSLER, F.
1902. CHEMISTRY OF THE TERPENES. Translated by Francis J. Pond. Rev. and enl., 457 p. Philadelphia.

(9) KAUFMAN, E. E.
1927. CALIFORNIA CROP REPORT FOR 1927. Calif. Dept. Agr. Mo. Bul. 16: 759–819.

(10) KONNERTH, R. A.
1926. HOW VARIED CONDITIONS AFFECT SOME ESSENTIAL OILS. Amer. Perfumer and Essential Oil Rev. 20: 695.

(11) MULLIKEN, S. P.
1904–22. A METHOD FOR THE IDENTIFICATION OF PURE ORGANIC COMPOUNDS BY A SYSTEMATIC ANALYTICAL PROCEDURE BASED ON PHYSICAL PROPERTIES AND CHEMICAL REACTIONS. 4 v., illus. New York and London.

(12) OGSTON, G. H., and MOORE.
1923. ALTERATION OF LEMON OIL ON KEEPING. Perfumery and Essential Oil Rec. 14: 7.

(13) PARKER, C. E., and HILTNER, R. S.
1918. AN IMPROVED METHOD FOR DETERMINING CITRAL. A MODIFICATION OF THE HILTNER METHOD. Jour. Indus. and Engin. Chem. 10: 608–610.

(14) PARRY, E. J.
1922. THE CHEMISTRY OF ESSENTIAL OIL AND ARTIFICIAL PERFUMES. Ed. 4, rev. and enl., 2 v. London.

(15) POORE, H. D.
1927. A MACHINE FOR THE PRODUCTION OF CITRUS OILS. Calif. Citrog. 12: 343–344, illus.

(16) REID, E. E.
1917. THE IDENTIFICATION OF ACIDS. Jour. Amer. Chem. Soc. 39: 124–136.

(17) ROMEO, G.
1925. SOPRA UNA SOSTANZA PRESUMIBILMENTE MUOVA DELL'ESSENZA DI LIMONE. Ann. Chim. Appl. [Rome] 15: 305–309.

(18) SALES, J. W.
1929. REPORT ON FLAVORS AND NON-ALCOHOLIC BEVERAGES. Jour. Assoc. Off. Agr. Chem. 12: 404–407.

(19) SCHIMMEL AND COMPANY.
1902. SEMIANNUAL REPORT OF SCHIMMEL & CO. (FRITZSCHE BROTHERS.) [CONCERNING PHARMACEUTICAL SUBSTANCES.] 105 p. Miltitz.

(20) SCHMIDT, E.
1901. UEBER DAS CITROPTEN. Apth. Ztg. 16: 619–620.

(21) SODEN, H. VON, and ROJAHN, W.
1901. UEBER NEUE CITRONENÖALDEHYDE. Ber. Deut. Chem. Gesell. 34: 2809–2829.
(22) STEPHAN, K.
1900. UEBER SÜSSES POMERANZENSCHALENÖL. Jour. Prakt. Chem. (n. F.) 62: 523–535.
(23) THEULIER, E.
1900. CITRAPTÈNE OU CAMPHRE DE CITRON. Rev. Gén. Chim. Pure et Appl. 3: 421–422.
(24) WALLACH, O.
1885. ZUR KENNTNISS DER TERPENE UND DER ÄTHERISCHEN OELE. Liebigs Ann. Chem. 230: 225–272.

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UNITED STATES DEPARTMENT OF AGRICULTURE
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BIOLOGY OF THE INDIAN-MEAL MOTH ON DRIED FRUITS IN CALIFORNIA

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CONTENTS

	Page
Introduction	1
History and distribution	2
Description of stages of the Indian-meal moth	2
The egg	2
The larva	2
The pupa	3
The adult	3
Food habits	3
Nature of damage	4
Plan of biological studies	4
Rearing methods	5
Seasonal history	6
Pupation of overwintered larvae	7
Seasonal history—Continued.	
Emergence of spring adults	8
Life-history studies	9
The adult	9
The egg	13
The larva	15
The pupa	18
Length of life cycle	19
Number of generations per year	22
Parasites	23
Summary	24
Literature cited	26

INTRODUCTION

The Indian-meal moth (*Plodia interpunctella* Huebner) [3] is one of the most destructive pests attacking dried fruits in storage in California. It has been found in varying numbers in every dried-fruit packing establishment examined.

An economic investigation of the insect pests of dried fruits in California was undertaken in July, 1922. The general remedial measures needed were quite obvious in view of the conditions of storage, state of entomological sanitation, and packing-house routine encountered, and varied control experiments under different conditions were promptly initiated.

Later, in September, 1925, a study of the biology of the Indian-meal moth was undertaken to reveal any unusual features of its life which might be valuable from the control viewpoint, to determine its rate of multiplication, and to supply the literature with much-needed information on the life history of this important insect. During this study, which was completed in June, 1927, raisins, prunes, and figs were used as food.

[1] Doctor Hamlin, who was in charge of dried-fruit insect investigations in the Division of Stored Product Insects from July, 1924, to July, 1927, outlined and directed the study herein reported.

[2] Mr. Phillips was in charge of dried-fruit insect investigations from June, 1922, to November, 1923, when he resigned on account of ill health. The descriptions of the stages of the insect and valuable observations used in this bulletin are drawn from his work.

[3] Order Lepidoptera, family Phycitidae.

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Fresno, Calif., the center of the dried-fruit industry of the United States, was selected as the scene of operations. Fresno is situated in the San Joaquin Valley, an extensive district having unusual conditions of temperature and humidity. The summer temperatures are among the highest in the country, with a wide daily range, whereas the winter temperatures are moderate. Atmospheric moisture is extremely low during summer and extremely high in winter, its range between these seasons being greater than that in any other district of the United States. These conditions combine to make the valley suited to dried-fruit production and are likewise important factors in insect development.

HISTORY AND DISTRIBUTION

Working in the Sacramento Valley, the climate of which is very similar to that of the San Joaquin Valley, Parker (*20*)[4] published in 1915 brief notes on the biology of the Indian-meal moth. As early as 1895, Chittenden (*4, p. 285*) had recorded the species as a pest of dried fruits, and since that time further mention of its relationship to dried fruits has been made by De Ong (*6, 7*), Essig (*10; 11, p. 712*) and Lovett (*19*).

The identity of the Indian-meal moth has been confused in many early citations, so that references to it can not always be separated from those relating to *Ephestia kuehniella* Zell., the Mediterranean flour moth. This confusion led to an article by Riley and Howard (*22*) in 1889 setting forth the distinguishing characters of the two species. *Plodia interpunctella* was first described by Huebner in 1827 (*16, Pl. 45*). It was redescribed by Fitch (*12, p. 320*) in 1856 under the name of *Tinea zeae*, and by Gregson (*14, p. 318*) in 1873 as *Ephestia roxburghii*. Since that time it has also been known under the names of *Ephestia zeae* and *Ephestia interpunctella*.

Fitch was the first to refer to this species as the Indian-meal moth, giving it this name because he found the larvae feeding in corn meal. Other common names, such as peach worm and pantry moth, have been used by different writers.

The Indian-meal moth is a native of the Old World. Hulst (*17, p. 201*) says that it is found everywhere, and indeed its food habits and adaptability to varying conditions have assured an almost universal distribution.

DESCRIPTION OF STAGES OF THE INDIAN-MEAL MOTH

THE EGG

The egg is grayish-white, ranging from 0.3 to 0.5 millimeter in length and almost perfectly ovate. The surface, as seen through the binocular microscope, shows a granular texture which diffracts light in many colors. The wall itself is not wholly opaque, as the developing larva may often be seen inside.

THE LARVA

The larvae vary much in size and coloration. When full grown they average about 13 millimeters in length but range from about 9 to 19 millimeters. Most specimens are a dirty white, but many vary toward a pinkish-brown or greenish tinge. These color variations are doubtless due in large part to the nature of the food.

The well-defined prothoracic shield is pale brown and is distinctly divided into lateral halves by a line of lighter color. The anal segment bears a dorsal plate of about the same color as the prothoracic shield. Ten abdominal segments are

[4] Italic numbers in parentheses refer to Literature cited, p. 26.

present, the third to the sixth, and the last, each bearing a pair of short prolegs. These are conical and terminate in an oval fringe of hooklets. Spiracles are present on the prothorax and on each abdominal segment except the ninth and tenth. The whole body is sparsely covered with long, fine hairs. The skin surface of the larva is slightly granular. Newly hatched larvae are only slightly over 1 millimeter in length, and this, together with their transparency, renders them very inconspicuous to the unaided eye.

THE PUPA

The light-brown pupa has a glossy surface throughout, the sutures being marked by fine lines of a darker color. Generally the posterior half is darker. During the early part of the period, the pupa is straw colored on the ventral surface and along the sides, ranging to light brown on the dorsal surface. In its later development there is a general darkening, especially in the wing regions, which become almost black just before emergence. The developing compound eyes are large and prominent, first showing dark brown and gradually changing to black. The pupae range in length from about 6 to 11 mm.

The pupae are ordinarily inclosed in silken cocoons, but naked individuals are occasionally found.

THE ADULT

The adult insect is of moderate size and distinctive coloration. The average wing expanse is about 16 mm. The basal half, or a little less, of the fore wings is a silvery white or gray with occasional minute dark spots; the outer portion is a reddish bronze with irregular dark bands. The hind wings are uniformly silver gray with a long silky fringe. This fringe is much longer on the inner margin, and its base shows a narrow band of lighter color, giving it a detached appearance. The abdomen is much the same color as the hind wings, and the thorax somewhat darker with a cloak of reddish scales anteriorly. The hind tibiae are robust. The slightly tapering antennae are slender and measure nearly two-thirds the length of the body.

This moth is easily distinguished from others of similar habits, with the possible exceptions of *Ephestia kuehniella* Zeller and *E. cautella* Walker; but these species are less strikingly marked and present much less color contrast in the fore wing. In cases where the color pattern of the wings does not suffice for distinguishing the species, the generic differences in the palpi provide an excellent means of separating the Indian-meal moth from the other two species. In the former the palpi extend forward horizontally and with a tuft of scales form a sort of beaklike cone about the length of the head, whereas in Ephestia they are erect.

FOOD HABITS

The Indian-meal moth is one of the most general feeders among insects attacking stored products. It has been reported as feeding upon grain and grain products, garden seeds, graham crackers, dried fruits, preserved fruits, nuts, edible acorns, dried vegetables, dandelion roots, garlic heads, dried botanical specimens, dried insects, beebread, yeast cakes, powdered milk, spices, cinnamon bark, cacao beans, sweetened chocolate, chocolate marshmallows, and other candies. Larvae introduced into a jar containing raisins, dates, dried peaches, apricots, and figs became uniformly distributed throughout the mass, with the exception that the raisins were somewhat less attacked.

Several instances of cannibalism have been observed. Most of the individuals fed upon were pupae or quiescent larvae in cocoons. The attack on pupae was more common, the contents of the abdomen being partially or entirely consumed. These cases of cannibalism occurred mainly in crowded rearings, and it is doubtless infrequent in nature except in packing houses supporting very heavy larval infestations, such as prevailed at Fresno in 1926 and 1927.

Immediately after hatching, even upon suitable food, the tiny larvae begin to disperse. Within a few hours they begin feeding and establish themselves in various ways upon different types and conditions of dried fruits. On raisins and prunes they place themselves

in crevices of the wrinkled exterior, where they puncture the skin and feed superficially within or near a tunnellike case formed of frass thrown out and webbed together with silk. An individual may construct more than one such tunnel. On processed figs, also, which are relatively soft and moist and form a compact mass, the attack is made chiefly upon the exterior in small crevices between individual figs. Thus the insect is essentially a superficial feeder, although on processed raisins small larvae occasionally enter at the point from which the stem has been removed and burrow into the center of the berry, and also on stored raw-stock figs they enter through the "eye"[5] of the fruit, which is externally tough and dry, and infest chiefly the interior.

After feeding is completed the grown larvae crawl to the surface of masses of dried fruit stored in piles or in bins, where they are conspicuous against a dark background. Some larvae spin cocoons near the surface of the fruit mass, and others in near-by cracks of bins, walls, stored box shooks, and elsewhere.

NATURE OF DAMAGE

The Indian-meal moth causes serious losses to the dried-fruit industry each year. These losses arise not so much from the quantity eaten by the insect as from the lowering of quality and the extra expense involved in processing the fruit before it is marketed. Fruit infested by this species not only contains living worms, but is increasingly polluted by excrement, cast skins, webbing, dead individuals, and often the cocoons of parasites. Back and Cotton (*1, p. 23*) have illustrated webs spun on corn made by well-grown larvae. Production expense is increased by the need of fumigation and the extra handling involved, and sometimes great loss results from the rejection or seizure of shipments.

Beyond these more or less direct losses is the greater, though less tangible, detriment to the industry through curtailment of the market for dried fruits by public discrimination against wormy fruit (*8*). Even a few larvae in a package may by their profuse webbing give to the contents a very repulsive appearance. These contaminated packages are usually not returned, the housewife discarding them and taking the immediate loss. These, however, become practically direct losses to the dried-fruit producers through subsequent discrimination against the brand involved.

During a period of exceptional abundance of the Indian-meal moth in the spring of 1927, figs in carried-over crops from three packing houses showed contamination by this species alone of 12, 19, and 23.2 per cent, with an average of 18 per cent. Lovett (*19, p. 119*) reported that English walnuts held in storage for eight months have developed as high as 95 per cent infestation. Such injury results in serious loss to the owners of the infested material.

PLAN OF BIOLOGICAL STUDIES

Before undertaking the biological study it had been noted that much variation in the intensity of infestation existed between different packing houses. These differences were due in part to conditions of handling and storage of the fruit, and appeared also to be related to

[5] The entire fig is a modified hollow stem bearing the flowers on the inside, and the so-called eye is the orifice at the outer end of this inflorescence receptacle.

the kind of fruit stored. Figs seemed to be more abundantly infested by this species than the other dried fruits. Accordingly the study was designed to reveal differential rates of development on raisins, prunes, and figs, these being the more important products in the San Joaquin Valley; as well as the rate of multiplication of the species and its life history and seasonal relations.

For convenience in determining the rate of multiplication the successive generations [6] were segregated in the laboratory. Thus, except in one instance, rearings for each generation were made from among the earlier emerged moths of the preceding generation. But, while useful for determining theoretical increase, the generational data are of secondary practical importance, since there is no separation of generations in nature. The data are therefore arranged primarily with reference to seasonal conditions.

The study was initiated with larvae hatched in the fall of 1925, which were reared through the winter in individual containers. In the spring of 1926 several of the earlier emerged female moths were mated shortly after emergence with males that emerged at very nearly the same time. Records were made of the longevity of mated pairs, the daily deposition of eggs by individual females, and of the hatching of the daily lots of eggs laid by each female. This general procedure was followed in all of the subsequent laboratory generations.

The dried fruits used as food in this study were seedless raisins, prunes, and Calimyrna figs (commercial name for the Lob Ingir or common Smyrna fig as grown in California), all processed. The data on raisins, being most complete, are presented in detail and comparison is made, where warranted, with the corresponding data on prunes and figs.

When moths from a particular generation and fruit were unobtainable, others of similar generational status from parallel or bulk rearings on the other fruits were substituted.

The excessively low humidity in the open air during the summer in the San Joaquin Valley is doubtless tempered somewhat within the masses of dried fruit, near the surface of which the larvae live. It was not practicable, however, to provide such masses of fruit in the individual laboratory rearings. Therefore, all rearings were conducted in a tightly closed laboratory room in which the atmospheric moisture was slightly increased by evaporation from a water surface of approximately 2 square feet. Effort was made to maintain the relative humidity at about 40 per cent, and this was fairly closely approximated. This procedure was employed from April 15, 1926, when the natural humidity began to decrease severely, until the following fall, when the outside humidity again increased above 40 per cent. The temperature in this room deviated but slightly from that in the other, unhumidified, parts of the laboratory.

The temperature and humidity in the rearing room were recorded by a hygrothermograph. Both conditions have been recorded in the accompanying tables, but, since the relative humidity varied inversely with the temperature, only the latter factor will be mentioned in discussing the various activities of the insect.

REARING METHODS

Oviposition and hatching took place in "capsule vials," 4⅛ inches in length and 1 inch in diameter, fitted with compression metal caps. In each vial a pair of moths was confined with a small quantity of

[6] The term "generation" refers to a complete egg-larva-pupa-adult cycle.

uninfested fruit for one day. On the following day the fruit was examined for eggs, and if any were found it was replaced in the same vial, which then served as an incubation cage. The moths were transferred to a similar vial for the succeeding day's oviposition. A covering of batiste, a thin, closely woven cloth, held in place by a rubber band now replaced the metal cap. The counting of eggs was facilitated and danger of their displacement lessened by handling the prunes and figs with forceps and by impaling the raisins upon insect pins.

Hatching records were made by daily count and removal of all larvae from the incubation vials. Examination was discontinued after 21 days from the initial hatching in each instance because it was established that eggs not hatched in that interval became so severely shriveled and discolored as to preclude the possibility of hatching.

Larval rearings were established with newly hatched larvae from the incubation vials. The larvae were confined with fruit in white, opaque glass jars 2 inches deep and 2 inches in diameter, fitted with metal screw tops.

SEASONAL HISTORY

The Indian-meal moth passes the mild California winter in the larval stage in unheated situations. The rate of development is irregular, the larvae ranging from one-eighth to five-eighths of an inch in length by midwinter, when all become inactive for a period of approximately three weeks. Pupation of the overwintered larvae begins early in March and ends during the latter half of May, the adults emerging from late March to the end of May. Eggs laid by the moths that were among the first to issue in the spring hatched, and the larvae from these matured during the latter half of May. Thus at the very outset there is opportunity for the mixing of generations, since both the more retarded overwintered individuals and the more advanced ones of the first summer generation issue as adults during the latter half of May.

This irregularity of development obtains with succeeding generations, with the result that in nature the generational status of individuals is thoroughly confused. All stages of the insect may be found in stored dried fruit from spring to fall.

All eggs hatching as late as June produce adults the same summer. Of those which hatch later, an increasing percentage, and virtually all of those hatching in the fall, overwinter as larvae and produce the spring brood of moths the following year.

In the fall of 1925, individual rearings were started with newly hatched larvae on raisins, prunes, and figs, 200 on each fruit. These larvae hatched in the period from September 25 to October 3.

The overwintering larvae were examined five times at approximately 3-week intervals from December 9, 1925, to March 3, 1926. When examined January 20 to 22, 1926, all were inactive and were of approximately the same size as when examined December 31, 1925, to January 2, 1926, at which time also nearly all were inactive. The mean temperature between these examinations was 47° F. There is thus a period of at least three weeks in midwinter when the larvae do little, if any, feeding. Some of the inactive larvae were in cocoons, whereas others were dormant in their feeding tunnels. Bioletti (*2, p. 3*) has said, "It is probable that the insect passes the winter in this [the pupal] stage, but in warm situations the larvae may live over the winter." The writers have observed no pupae overwintering.

The rate of development was very uneven. Thus, on March 3, 1926, a considerable percentage of larvae on each fruit was only one-fourth inch in length, and on prunes one individual was one-eighth inch long, while the great majority on each fruit were from three-eighths to one-half inch, and a very few specimens five-eighths inch in length. The larvae feeding on figs averaged slightly larger at each examination than those on raisins and prunes. This more rapid development on figs is discussed on page 17.

PUPATION OF THE OVERWINTERED LARVAE

Table 1 shows the dates of pupation of the 293 overwintered individuals which later produced adults. This table also shows the cumulative percentages which had pupated on each date of the pupation period, extending from March 6 to May 20, 1926. The great majority of these larvae pupated during March.

TABLE 1.—*Pupation of overwintered larvae of the Indian-meal moth reared on raisins, prunes, and figs, Fresno, Calif., 1926* [1]

Date of pupation [2]	Pupation record						Daily temperature			Mean relative humidity
	Reared on raisins: Larvae hatched Sept. 25–26, 1925		Reared on prunes: Larvae hatched Sept. 26–30, 1925		Reared on figs: Larvae hatched Sept. 30–Oct. 3, 1925					
	Number pupated	Cumulative percentage pupated	Number pupated	Cumulative percentage pupated	Number pupated	Cumulative percentage pupated	Maximum	Minimum	Mean	
							°F.	°F.	°F.	*Per cent*
Mar. 6	1	0.9					74	55	65	73
Mar. 9	1	1.8	2	2.2	1	1.1	66	55	61	68
Mar. 10			6	8.9	7	9.0	72	50	61	64
Mar. 11	5	6.1	6	15.6	4	13.5	76	52	64	61
Mar. 12	4	9.6	4	20.0	7	21.3	77	53	65	61
Mar. 13	7	11.4	2	22.2	8	30.3	80	53	67	60
Mar. 14	3	14.0	3	25.6	4	34.8	83	56	70	66
Mar. 15	3	16.7	9	35.6	7	42.7	81	57	69	58
Mar. 16	4	20.2	8	44.4	8	51.7	78	58	68	57
Mar. 17	5	24.6	4	48.9	2	53.9	72	59	66	54
Mar. 18	6	29.8	2	51.1	1	55.1	71	56	64	58
Mar. 19	3	32.5	1	52.2	4	59.6	74	60	67	54
Mar. 20	3	35.1	5	57.8	1	60.7	77	59	68	54
Mar. 21	6	40.4	4	62.2	5	66.3	77	59	68	48
Mar. 22	5	44.7	5	67.8	1	67.4	85	57	71	42
Mar. 23	3	47.4	3	71.1	5	73.0	86	58	72	43
Mar. 24	3	50.0	2	73.3	2	75.3	86	61	74	46
Mar. 25	7	56.1	2	75.6	3	78.7	82	59	71	44
Mar. 26	3	58.8	3	78.9	2	80.9	80	58	69	37
Mar. 27	2	60.5	6	85.6	2	83.1	83	56	70	40
Mar. 28	3	63.2	1	86.7	4	87.6	80	57	69	43
Mar. 29	10	71.9	1	87.8	2	89.9	83	58	71	43
Mar. 30	3	74.6	1	88.9	2	92.1	85	57	71	40
Mar. 31	2	76.3	4	93.3	2	94.4	86	59	73	46
Apr. 1	1	77.2	1	94.4	1	95.5	74	61	68	45
Apr. 2	1	78.1	1	95.6	1	96.6	70	58	64	46
Apr. 5	3	80.7					71	62	67	66
Apr. 6	2	82.5			1	97.8	72	62	67	67
Apr. 8	1	83.3					66	58	62	70
Apr. 12	1	84.2					81	55	68	61
Apr. 13	1	85.1					85	60	73	60
Apr. 14	2	86.8					86	63	75	61
Apr. 15	2	88.6			1	98.9	85	67	76	56
Apr. 16	4	92.1	1	96.7			85	65	75	49
Apr. 19			1	97.8	1	100.0	76	58	67	62
Apr. 21	1	93.0	1	98.9			84	64	74	62
Apr. 22	1	93.9					84	65	75	58
Apr. 24	1	94.7					91	68	80	57
Apr. 27	3	97.4					93	74	84	52
Apr. 28	1	98.2					92	74	83	52
May 5			1	100.0			77	65	71	49
May 9	1	99.1					78	57	68	45
May 10	1	100.0					84	60	72	41
Total	114		90		89					

[1] Approximately 5 per cent of those which pupated did not emerge. These have been omitted.
[2] Dates on which no larvae pupated have been omitted from the table.

From Table 1 it is also apparent that pupation of individuals reared on raisins lagged considerably behind that of larvae reared on prunes and figs; for instance, on March 31, over 93 per cent of the latter had pupated as compared with 76.3 per cent of the former.

EMERGENCE OF SPRING ADULTS

Table 2 shows the emergence of spring adults resulting from overwintered individuals. Here it is seen that emergence was very uneven, being spread over a period of two months.

TABLE 2.—*Emergence of spring adults of the Indian-meal moth, Fresno, Calif., 1926*

Date of emergence [1]	Emergence of spring adults from larvae reared on—						Daily temperature			Daily mean relative humidity
	Raisins		Prunes		Figs					
	Number emerged	Cumulative percentage emerged	Number emerged	Cumulative percentage emerged	Number emerged	Cumulative percentage emerged	Maximum	Minimum	Mean	
							°F.	°F.	°F.	*Per cent*
Mar. 30	1	0.9					85	57	71	40
Mar. 31	2	2.6	2	2.2	3	3.4	86	59	73	46
Apr. 1	2	4.4	8	11.1	1	4.5	74	61	68	45
Apr. 2	1	5.3	5	16.7	2	6.7	70	58	64	46
Apr. 3	1	6.1	1	17.8	5	12.4	73	58	66	50
Apr. 4	1	7.0	2	20.0	2	14.6	66	60	63	55
Apr. 5	3	9.6	3	23.3	6	21.3	71	62	67	66
Apr. 6	1	10.5	1	24.4			72	62	67	67
Apr. 7	3	13.2	3	27.8	1	22.5	67	62	65	68
Apr. 8	3	15.8	6	34.4	9	32.6	66	58	62	70
Apr. 9	5	20.2	9	44.4	3	36.0	72	52	62	68
Apr. 10	3	22.8	4	48.9	13	50.6	75	56	66	67
Apr. 11	4	26.3			3	53.9	69	57	63	67
Apr. 12	8	33.3	6	55.6	5	59.6	81	55	68	61
Apr. 13	5	37.7	4	60.0	7	67.4	85	60	73	60
Apr. 14	6	43.0	4	64.4	2	69.7	86	63	75	61
Apr. 15	5	47.4	7	72.2	6	76.4	85	67	76	56
Apr. 16	8	54.4	2	74.4	4	80.9	85	65	75	49
Apr. 17	5	58.8	9	84.4	5	86.5	75	66	71	53
Apr. 18	3	61.4			3	89.9	71	61	66	57
Apr. 19	5	65.8	1	85.6			76	58	67	62
Apr. 20	6	71.1	1	86.7			81	61	71	62
Apr. 21	4	74.6	3	90.0	3	93.3	84	64	74	62
Apr. 22	3	77.2	2	92.2	1	94.4	84	65	75	58
Apr. 23	3	79.8	3	95.6	2	96.6	88	65	77	59
Apr. 26	2	81.6					98	73	86	53
Apr. 27	5	86.0			1	97.8	93	74	84	52
Apr. 28	6	91.2	1	96.7	1	98.9	92	74	83	52
Apr. 30	2	93.0	1	97.8			86	69	78	51
May 1					1	100.0	83	66	75	51
May 5	2	94.7	1	98.9			77	65	71	49
May 11	2	96.5					90	65	78	42
May 12	1	97.4					93	67	80	44
May 14	1	98.2					88	65	77	44
May 19			1	100.0			94	76	85	42
May 20	1	99.1					90	70	80	42
May 30	1	100.0					96	74	85	40
Total	114		90		89					

[1] Dates on which no moths emerged have been omitted from the table.

The period of emergence of individuals reared on raisins began earlier and ended later than that of those reared on prunes and figs. During the major emergence period, from March 30 to April 21, only 74.6 per cent of the raisin-fed individuals emerged, as compared with 90 per cent or more of those fed on prunes and figs. These figures agree reasonably well with observations upon the emergence of moths in packing houses.

Although emergence was slower in the raisin rearings, it was more complete, 57 per cent of them producing adults, as compared with approximately 45 per cent of those reared on prunes and figs. The earlier emerged of these spring moths produced the eggs used in initiating the life-history studies.

LIFE-HISTORY STUDIES

THE ADULT

COPULATION

Copulation may occur in 1 hour after emergence and ordinarily does occur within 24 hours. When an unmated male and female are placed together in a vial some hours after emergence they usually copulate readily, the observed interval ranging from one-half to 255 minutes. The moths remain in copulation from 10 to 120 minutes.

PREOVIPOSITION PERIOD

The interval from the emergence of female moths to initial oviposition ranged from less than a day [7] to 9 days in the period between March 31 and October 20, 1926.

Females which emerged during the cool weather from March 31 to April 8 laid their first eggs after intervals of 1 to 9 days from mating (Table 3), the preoviposition period averaging 2.9 days. During the period from June to August, inclusive, marked by high temperatures, the preoviposition period ranged from 0 to 2 days (Table 4), and averaged 0.5 day. Females which emerged in September and October, when the temperatures were intermediate between those of spring and midsummer, oviposited initially after intervals of 0 to 3 days from mating (Table 5), the average preoviposition interval being 1.1 days.

TABLE 3.—*Oviposition of the Indian-meal moth on dried fruits, Fresno, Calif., spring observations, 1926*

Female No.	Fruit placed with moths	Date female mated [1]	Number of eggs deposited on specified number of days after mating [2]															Total number eggs laid	Mean temperature [3]	Mean relative humidity [3]
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
																			°F.	*Per cent*
1	Raisins	Mar. 31	--	--	--	83	0	17	16	0	9	12	0	0	5	4	0	146	67	60
2	Prunes	do	--	--	--	103	17	28	30	27	0	28	9	0	12	4	--	258	66	60
3	do	Apr. 1	--	--	101	0	24	14	8	0	8	0	--	--	--	--	--	155	65	60
4	do	do	--	--	61	26	0	45	18	2	12	10	1	9	5	4	3	196	67	60
5	do	do	--	--	--	--	--	--	--	--	91	18	0	11	3	0	--	123	66	61
6	do	Apr. 2	--	--	--	114	0	56	8	22	0	13	11	9	--	--	--	233	65	62
7	Figs	Apr. 3	--	--	--	--	--	--	--	--	--	62	58	117	2	0	--	239	68	62
8	do	do	--	--	--	94	47	5	6	47	24	13	6	5	3	--	--	250	67	63
9	do	Apr. 8	--	73	0	47	32	8	7	0	--	--	--	--	--	--	--	167	68	63
10	do	do	--	16	46	4	36	30	0	0	0	--	--	--	--	--	--	132	69	62
11	Raisins	do.[4]	--	28	7	10	15	28	22	10	6	0	--	--	--	--	--	126	69	61
12	do	do.[4]	--	--	55	0	24	22	11	13	0	0	--	--	--	--	--	125	69	61
13	do	do.[5]	--	72	0	0	10	16	17	9	0	--	--	--	--	--	--	124	69	62
14	do	do	--	--	21	0	25	32	16	0	0	--	--	--	--	--	--	94	69	62
	Average number eggs per female																	169.1	--------	--------
	Average eggs per female per day (for entire life)																	14.6	--------	--------

[1] Females mated on day of emergence except as noted.
[2] Last record (either significant figures or zero) made on day of death.
[3] From date mated to date of death.
[4] Female emerged day before mated.
[5] Female emerged two days before mated.

The preoviposition period of the 70 females from which the ranges and averages were derived may be found in Tables 3, 4, and 5 by noting the number of blank spaces preceding the first egg record for each moth.

[7] When oviposition occurred during the first day after mating that day was included in the oviposition period, and the preoviposition period was recorded as zero.

OVIPOSITION

The eggs are placed singly or in rough clusters or chains, aggregating as many as 30 eggs, over the surface of dried fruits, being mostly deposited in crevices of the wrinkled skins. In the case of figs, eggs are occasionally deposited inside the eye. Under laboratory conditions the eggs were especially abundant on the sides of the fruit just above the supporting surface. Lovett (*19, p. 119*) stated that eggs are deposited also on food cartons or containers, or on walls, floors, or similar situations adjacent to the food product. Oviposition is chiefly nocturnal, as reported by Parker (*20, p. 4*); however, during the first three days of egg laying the female is likely to deposit some eggs in the daytime.

TABLE 4.—*Oviposition of the Indian-meal moth on dried fruits, Fresno, Calif., summer observations, 1926*

Female No.	Fruit placed with moths	Date female mated [1]	Number of eggs deposited, on specified number of days after mating [2]									Total number eggs laid	Mean temperature [3]	Mean relative humidity [3]
			1	2	3	4	5	6	7	8	9			
													° *F.*	*Per cent*
1	Raisins	June 3	----	58	----	----	----	----	----	----	----	58	87	41
2	---do	---do	39	0	----	----	----	----	----	----	----	39	87	41
3	---do	June 7	37	17	11	7	0	----	----	----	----	72	82	45
4	---do	---do	----	101	28	----	----	----	----	----	----	129	82	45
5	Prunes	June 8 [4]	57	19	63	0	15	0	----	----	----	154	81	43
6	---do	---do.[4]	58	29	19	13	0	0	----	----	----	119	81	43
7	---do	---do.[4]	----	70	7	0	0	----	----	----	----	77	82	44
8	---do	---do	----	77	31	0	17	0	0	----	----	125	81	43
9	Figs	June 10	134	16	35	0	0	----	----	----	----	185	81	41
10	---do	June 11	----	128	3	0	0	0	----	----	----	131	79	41
11	---do	June 12	97	71	78	0	0	29	0	0	0	275	79	41
12	Raisins	June 14	32	28	0	0	0	----	----	----	----	60	79	42
13	Prunes	June 15	----	48	28	21	0	14	----	----	----	111	79	42
14	Raisins	July 9 [4]	12	98	39	0	----	----	----	----	----	149	87	42
15	---do	---do.[4]	----	88	28	5	0	----	----	----	----	121	87	43
16	---do	July 19	----	85	15	0	0	----	----	----	----	100	87	35
17	---do	July 21	81	45	23	0	0	----	----	----	----	149	86	37
18	---do	---do	----	52	15	1	0	----	----	----	----	68	86	37
19	Prunes	July 24	89	42	33	6	0	0	----	----	----	170	85	39
20	---do	---do	19	24	14	5	5	0	----	----	----	67	85	39
21	---do	July 25	----	----	51	11	9	----	----	----	----	71	85	39
22	Figs	---do	10	20	59	14	0	----	----	----	----	103	85	39
23	---do	July 27	52	73	34	0	----	----	----	----	----	159	85	42
24	---do	July 31	----	79	40	12	----	----	----	----	----	131	90	39
25	---do	Aug. 8	----	61	18	8	0	0	0	----	----	87	85	40
26	Prunes	Aug. 13	14	9	28	21	8	7	0	0	----	87	85	40
27	Raisins	Aug. 16	62	64	24	9	0	----	----	----	----	159	84	41
28	---do	Aug. 20	----	132	44	9	0	----	----	----	----	185	85	42
29	---do	Aug. 21	120	69	40	17	0	----	----	----	----	246	84	41
30	Prunes	Aug. 25	----	27	32	26	8	2	6	0	----	101	80	43
31	Raisins	Aug. 28	4	104	26	9	7	0	----	----	----	150	80	43
32	Figs	---do	----	----	109	40	32	9	0	0	----	190	80	43
33	Raisins	Aug. 30	74	24	39	22	6	0	0	----	----	165	80	43
	Average number eggs per female											127.1	----	----
	Average eggs per female per day (for entire life)											23.3	----	----

[1] Females mated on day of emergence except as noted.
[2] Last record (either significant figure or zero) made on day of death.
[3] From date mated to date of death.
[4] Female emerged day before mated.

The eggs are seldom firmly attached to the fruit surface. A slight shake will usually dislodge them from dried fruits that are not sticky. It is especially important in the processing of seedless raisins, which involves no heat treatment, that the usual mechanical agitation and washing in a stream of water may suffice to dislodge the great majority of eggs of this species.

The egg laying of 70 females which emerged between March 31 and October 20 is recorded in Tables 3, 4, and 5. Here it may be noted that on the last of March and in early April (Table 3) the oviposition

lasted from the second to the fifteenth day after mating, approximately 90 per cent of the eggs, however, being laid from the second to the eleventh day, inclusive. These moths, living under mean temperatures in the 60's, laid from 94 to 258 eggs each, the average being 169.1, an average of 14.6 eggs per day during entire life.

The females which emerged in the period from June to August, inclusive (Table 4), lived under means of temperature mostly in the 80's. During this hot, dry season the oviposition period was reduced to about one-half that of the spring months, and ranged from the first to the seventh day after mating. Approximately 90 per cent of the eggs were deposited during the first three days. Individual production decreased, the moths laying from 39 to 275 eggs, with an average of 127.1, whereas the rate of deposition, expressed as the average number of eggs per female per day for the entire life, was approximately 60 per cent higher than the average during the spring months, being 23.3.

During September and October (Table 5) the means of temperature were intermediate between those of spring and those of midsummer, being mostly in the 70's. Under these conditions the females oviposited from 1 to 20 days after mating. Approximately 90 per cent of the eggs were laid during the first 6 days. Individual totals ranged from 80 to 246 eggs, with an average of 178.3 eggs. The average number of eggs per female per day for the entire life was 15.7. Thus, in general, the activities of moths at this season may be regarded as intermediate between those of spring and midsummer.

TABLE 5.—*Oviposition of the Indian-meal moth on dried fruits, Fresno, Calif., fall observations, 1926*

Female No.	Fruit placed with moths	Date female mated [1]	Number of eggs deposited, on specified number of days after mating [2]																				Total number eggs laid	Mean temperature [3]	Mean relative humidity [3]
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
																								°F.	*Per cent*
1	Figs	Sept. 4		144	32	19	3	4	0														202	81	46
2	Prunes	Sept. 11		90	51	36	18	4	4	2	2	0											207	73	46
3	Figs	Sept. 16		74	24	37	0	28	0	0	0												163	73	46
4	Prunes	do		96	39	21	11	8	8	3	2	0											188	73	45
5	do	Sept. 18		30	34	26	15	20	0	4	0	0	0	0	0	0	0	0	0	2	0		131	72	49
6	Figs	Sept. 23			93	15	23	12	0	4	0	0	0	0									147	71	49
7	Prunes	Sept. 24			76	52	16	4	6	0	0	0											154	71	48
8	do	Sept. 26		73	40	0	32	9	12	12	6	4	0	0									188	72	51
9	do	do		30	64	7	21	14	19	5	8	3	0	0									171	72	51
10	do	Oct. 5	31	46	35	19	14	0	7	2	3	0	0	0	0	0							157	71	56
11	do	do	83	134	0	20	2	0	0														239	70	54
12	Raisins	do	22	30	7	16	0	5	0	0	0												80	70	55
13	do	Oct. 7			52	31	12	30	24	13	9	5	0	1	0	0	0	0	0	0	0	[4] 2	179	69	60
14	do	Oct. 8 [5]		40	23	13	16	11	19	7	0	0	0	0									129	70	57
15	do	do			50	21	23	23	32	6	7	21	13	5	4	4	4	0					213	69	59
16	Prunes	do [5]		86	27	26	24	17	14	4	0	0	0										198	70	57
17	do	Oct. 11		68	65	24	17	9	3	0													186	71	59
18	Raisins	do				89	10	20	24	9	0	0	0										152	70	60
19	do	Oct. 14	63	60	37	7	21	1	0	0													189	71	61
20	do	Oct. 17	70	27	36	35	23	12	15	11	9	8	0	0									246	69	64
21	do	Oct. 19			104	31	30	21	27	12	14	5	0	1	0	0							243	67	63
22	Figs	Oct. 20		34	71	12	10	12	0														139	68	66
23	do	do		61	70	17	23	21	6	1													199	68	66
		Average number eggs per female																					178.3		
		Average eggs per female per day (for entire life)																					15.7		

[1] Females mated on day of emergence except as noted.
[2] Last record (either significant figure or zero) made on day of death.
[3] From date mated to date of death.
[4] Lived 3 days more without depositing additional eggs.
[5] Female emerged day before mated.

The number of eggs deposited by individual moths throughout the season ranged from 39 to 275, both the minimum and the maximum occurring in June. The seasonal average for the 70 females was 152.3 eggs. Several writers have placed the egg capacity much higher. Parker (*20, p. 4*) reported the average of 6 females as 221.3, the range being from 156 to 286. Chittenden (*5, p. 119*) reported the egg capacity as high as 350, and Essig (*11, p. 712*) stated that each female may deposit from 300 to 400 eggs.

The eggs may be extruded very rapidly. One female laid 144 eggs in one day (Table 5), and in the earlier work Phillips observed a female to deposit 115 eggs in a single hour.

The length of life of the female moths after oviposition was completed ranged from 0 to 5 days, with an average of 1.6 days.

LONGEVITY

The adult life of the Indian-meal moth is comparatively brief, and that it is profoundly influenced by seasonal conditions is evidenced by the data in Table 6. The length of life of mated males and females which emerged from March 31 to April 8 and lived under a mean temperature of 67° F. averaged 19.1 and 11.9 days, respectively. Mated moths which emerged from June to August experienced hot, dry weather, the mean temperature being 86°. The longevity then averaged but 5.8 and 5.2 days for males and females, respectively. During October, when the temperature averaged 68° F., the longevity of mated males averaged 13.3 days and that of mated females 11.6 days. Unmated males and females lived on the average 2.4 and 2.7 days longer, respectively, than mated individuals of corresponding sex and males 2 to 3 days longer than females, but analysis shows that these differences are not significant.

TABLE 6.—*Longevity of mated and unmated adults of the Indian-meal moth, Fresno Calif., 1926*

Period of emergence	Condition of moths	Males			Females			Mean temperature [1]	Mean relative humidity [1]
		Number	Days of life		Number	Days of life			
			Range	Mean		Range	Mean		
								°F.	*Per cent*
Mar. 31–Apr. 8	Mated	14	14–25	19.1	14	8–15	11.9	67	54
Mar. 31–Apr. 12	Unmated	30	14–24	19.1	30	9–20	15.2	65	60
June 3–Aug. 30	Mated	23	2–12	5.8	23	2–9	5.2	86	40
June 5–Aug. 31	Unmated	23	1–11	6.1	25	2–12	6.3	85	40
Oct. 5–Oct. 20	Mated	7	9–18	13.3	14	7–23	11.6	68	58
Oct. 2–Oct. 16	Unmated	9	8–18	13.7	7	8–21	14.3	70	60
	Mated	44	2–25	11.2	51	2–23	8.8	-------	-------
	Unmated	62	1–24	13.6	62	2–21	11.5	-------	-------

[1] For the period between extreme dates covered by the lives of all moths in each group.

HABITS

The adults avoid the light. During the day they rest quietly on walls, ceilings, and boxes in poorly lighted situations near stored dried fruit, in storage rooms, and between sweat boxes in storage sheds. When disturbed they fly readily in an irregular, zigzag course. The moths are chiefly night fliers; this tendency is readily apparent at dusk, for then the moths begin to fly about.

THE EGG

INCUBATION

The data presented in Table 7 deal with the larger daily groups of the eggs shown in Tables 3, 4, and 5. They show the range and weighted average of the incubation period for several lots of eggs deposited during each month, except May, from April to November, together with the means of temperature and relative humidity for the interval from egg deposition to initial hatching in each instance.

TABLE 7.—*Incubation periods of eggs of the Indian-meal moth, Fresno, Calif., 1926*

Date eggs were deposited	Eggs hatched	Incubation period		Mean temperature [1]	Mean relative humidity
		Range	Weighted mean		
	Number	*Days*	*Days*	*°F.*	*Per cent*
Apr. 4	330	10–13	10.4	65	65
Apr. 6	152	9–12	9.2	67	65
Apr. 7	154	9–12	9.2	68	64
Apr. 8	98	8–10	8.4	68	63
Apr. 10	270	7–14	7.9	71	60
Apr. 11	150	6–12	7.0	72	59
Apr. 13	225	5–12	6.4	74	56
Apr. 14	177	6–11	6.4	72	56
Apr. 15	153	6–12	7.1	71	56
Summary, Apr. 4–15	1,709	5–14	8.0	70	60
June 9	204	3– 8	4.5	82	47
June 10	225	2– 8	4.0	83	45
June 11	159	4– 7	4.9	80	40
June 13	163	3–10	4.7	78	41
June 15	48	4– 8	5.0	79	42
June 17	44	3– 5	3.3	81	42
June 19	13	4	4.0	82	39
Summary, June 9–19	856	2–10	4.3	81	42
July 11	166	3– 4	3.1	89	43
July 12	41	3– 4	3.4	90	43
July 21	77	3– 6	4.3	86	38
July 22	90	3– 5	4.0	85	38
July 23	55	4– 5	4.1	87	37
July 25	79	3– 5	3.2	86	37
July 26	52	3– 5	3.2	84	40
July 28	131	3– 6	3.9	85	43
July 29	45	3– 5	3.7	88	42
Summary, July 11–29	736	3– 6	3.7	87	40
Aug. 2	60	3– 5	3.3	90	40
Aug. 3	39	3– 6	3.9	90	39
Aug. 10	39	4– 5	4.2	84	42
Aug. 17	68	3– 5	3.6	84	43
Aug. 18	70	3– 6	3.3	84	45
Aug. 20	9	2– 4	2.9	84	43
Aug. 22	209	3– 5	3.5	85	42
Aug. 23	77	3– 5	3.5	86	41
Aug. 30	47	4– 8	4.6	79	43
Aug. 31	157	4– 7	4.2	81	43
Summary, Aug. 2–31	775	2– 7	3.7	85	42
Sept. 1	40	3– 6	4.1	82	43
Sept. 2	46	4– 5	4.2	82	44
Sept. 6	103	3– 4	3.6	81	46
Sept. 13	77	4– 9	5.1	76	45
Sept. 18	118	5– 6	5.1	73	46
Sept. 20	66	5– 9	6.0	73	44
Sept. 22	56	5– 7	5.3	74	43
Sept. 27	75	5– 8	5.7	70	46
Sept. 28	133	6– 8	6.6	69	52
Sept. 29	109	6– 8	6.5	69	55
Summary, Sept. 1–29	823	3– 9	5.2	75	46

[1] For the interval from egg deposition to initial hatching.

TABLE 7.—*Incubation periods of eggs of the Indian-meal moth, Fresno, Calif., 1926*—Continued

Date eggs were deposited	Eggs hatched	Incubation period		Mean temperature	Mean relative humidity
		Range	Weighted mean		
	Number	*Days*	*Days*	*°F.*	*Per cent*
Oct. 6	113	6–11	6.5	69	53
Oct. 7	149	6–11	7.1	68	54
Oct. 10	128	6– 9	6.3	70	58
Oct. 13	110	5– 7	5.4	72	59
Oct. 15	160	4– 9	5.4	72	59
Oct. 18	100	6– 8	6.2	68	64
Oct. 22	155	6– 8	6.3	68	66
Oct. 23	109	6– 7	6.1	69	66
Oct. 25	40	7– 9	7.1	67	62
Oct. 28	8	9–10	9.6	65	56
Oct. 31	1	12	12.0	63	54
Summary, Oct. 6–31	1,073	4–12	7.1	68	59
Nov. 17	19	14–15	14.1	60	75
Nov. 18	12	14–15	14.1	60	76
Nov. 20	16	14–15	14.2	60	79
Nov. 21	1	15	15.0	60	81
Nov. 22	5	16–17	16.2	59	83
Summary, Nov. 17–22	53	14–17	14.7	60	79

Table 7 shows clearly the great variation in the incubation period and its relationship to temperature. Thus, the average mean incubation period fell to 3.7 days during July and August when the means of temperature were mostly in the 80's, but with mean temperatures approximating 60° F. during November, the average mean incubation period rose to 14.7 days. During other months, temperatures intermediate between the above coincided with intermediate incubation periods.

The seasonal extremes of incubation were 2 and 17 days, the minimum occurring in June and again in August, and the maximum in November. It is worthy of note that the minimum occurred under the more moderate mean temperatures of from 83 to 84° and not at the higher temperature means ranging up to 90° F. Herms (*15*) has reported the incubation period as about 48 hours at a maintained temperature of 22 to 26° C. (72 to 79° F.). Lovett (*19, p. 119*) stated that the eggs hatch in about 4 to 8 days.

PERCENTAGE OF HATCH

Table 8 gives the percentage of hatch of 10,690 eggs, some of which were laid each month, except May, from April to early December. The record of each monthly group is compared with the mean temperature and humidity during its incubation period, measured from the oviposition of the first-laid eggs to the first hatch of the last laid daily group.

TABLE 8.—*Percentage of hatch of daily batches of eggs of the Indian-meal moth, Fresno, Calif., 1926*

Period of egg deposition	Total eggs laid	Percentage of eggs hatched		Mean temperature [2]	Mean relative humidity [2]
		Range [1]	Average		
		Per cent	*Per cent*	° *F.*	*Per cent*
Apr. 4–17	2,368	50.0–100.0	78.3	69	61
June 4–21	1,535	14.3–100.0	68.8	81	42
July 10–30	1,152	43.7– 94.0	73.7	83	39
Aug. 2–31	1,307	42.9–100.0	75.8	84	41
Sept. 1–30	1,588	19.6–100.0	72.3	75	47
Oct. 1–31	2,529	32.1– 90.8	70.8	68	58
Nov. 17–Dec. 4	211	0 – 67.9	25.1	59	78
Apr. 4–Oct. 31	[3] 10,479	14.3–100.0	73.4		

[1] Range here refers to percentages of hatch of daily batches of eggs (in excess of 10) laid by one or more moths from which the present group totals were derived.
[2] For the period from date of first oviposition to initial hatching of last laid eggs for each group.
[3] This total omits the 211 eggs laid in November and December under exceptional conditions.

From Table 8 it appears that the percentage of hatch was not greatly affected by the very high temperatures of midsummer, but was drastically reduced by low temperature. The eggs deposited in November were laid by a single exceptionally late-emerged female and are included solely to show the influence of temperature on hatching. The eggs of this moth hatched to the extent of only 25.1 per cent under a mean temperature of 59° F. During the main hatching period from April to October the maximum hatch of 78.3 per cent was in April under a mean temperature of 69°, and the minimum, 68.8 per cent in June, with a mean temperature of 81°.

Throughout the season the percentage of hatch of daily batches of eggs ranged from 0 to 100. Excluding the eggs laid in November, the average percentage of hatch for the season was 73.4 per cent.

THE LARVA

DURATION OF LARVAL PERIOD ON RAISINS

The length of larval life of the Indian-meal moth is highly variable, both individually and seasonally. The seasonal variations, however, appear to have no direct relation to the prevailing temperature.

The feature of Table 9 is the unequal rate of larval development. This inequality is expressed in two ways: (1) In the wide range of the larval period of those individuals which started life at the same time and all of which pupated during the same year; and, (2) in the fact that of larvae having the same parentage and hatching on or about the same date in one year, some individuals pupated that year whereas others wintered as larvae and pupated the following year. Thus, all the 114 larvae which hatched in September, 1925, pupated the following year, having larval periods ranging from 162 to 227 days. Here the slower individuals lived nearly half again as long in the larval stage as did the more advanced ones. The 20 larvae which hatched in April, 1926, pupated in 28 to 56 days, one extreme being just twice as long as the other, and the range of 16 individuals which hatched in June was 21 to 61 days, the extremes being nearly in the ratio of 3 to 1.

TABLE 9.—*Duration of larval life of the Indian-meal moth on ratsins, Fresno, Calif., 1925–1927*

Date eggs hatched	Total larvae	Transforming individuals					Wintering individuals				
		Larvae	Days of larval life		Mean temperature [1]	Mean relative humidity [1]	Larvae	Days of larval life		Mean temperature [1]	Mean relative humidity [1]
			Range	Average				Range	Average		
1925					°F.	*Per cent*				°F.	*Per cent*
Sept. 25–26	114	0	-------	-------	-------	-------	114	162–227	183.1	59	72
1926											
Apr. 14–17	20	20	28–56	39.9	76	48	0	-------	-------	-------	-------
June 9	16	16	21–61	36.2	85	39	0	-------	-------	-------	-------
July 14	23	22	29–74	44.1	86	40	1	282	282.0	66	64
Aug. 20–21	16	5	34–48	40.4	78	45	11	231–267	249.1	63	67
Oct. 16	14	0	-------	-------	-------	-------	14	159–188	172.6	58	74
Total, range, and average	203	63	21–74	40.5	-------	-------	140	159–282	[2] 209.2	-------	-------

[1] This mean is an average of the means for all larval periods within each group.
[2] This average excludes the 114 individuals reared in 1925 and is weighted in accordance with the seasonal trend exemplified by the three 1926 rearings.

When part of the group wintered as larvae, the range was of course greatly extended. Of 23 larvae hatching in July, 22 pupated in 29 to 74 days, but one passed the winter as a larva and pupated the following year, remaining 282 days in the larval stage. This approaches the maximum larval period encountered in the present study. From 16 larvae which hatched in August, 5 completed the larval stage in 34 to 48 days, and the remaining 11 required 231 to 267 days, pupating the following year. Finally, the 14 individuals which hatched in October all wintered as larvae, the range of the larval period being 159 to 188 days. Four of the larvae which hatched from August 20 to 21, 1926, pupated during May, 1927, whereas all the larvae which hatched nearly two months later on October 16, 1926, had pupated by April 22, 1927.

For purposes of comparison the larvae have been grouped according to the period in which they hatched (Table 9), but the reader has access to the larval period of each individual, except those overwintering in 1925–26, by reference to Table 12.

The lack of any relationship between the length of larval life and temperature should be obvious if attention were confined to the transforming individuals shown in Table 9. However, the mean larval period of individuals hatched in April was 39.9 days, and the average of the mean temperatures for all larval periods in this group was 76° F. With the much higher average of mean temperatures of 85°, the mean larval period of individuals hatched in June was only slightly reduced, being 36.2 days. Those larvae which hatched in July lived under an average of mean temperatures (86°) approximating that of the June hatch, but the mean larval period (44.1 days) was considerably longer than that of either the June or the April hatch. Finally, those which hatched in August had a mean larval life of 40.4 days, the average of mean temperatures in this case being 78°.

Lovett (*19, p. 119*) reported the average larval stage as about 60 days.

It thus appears that temperature, while probably influencing the length of larval life to some extent, is of distinctly secondary importance to other factors governing the length of the larval period. For instance, all the 23 larvae which hatched on July 14 lived under similar temperature conditions during the first 29 days of life; yet one individual pupated on the twenty-ninth day, whereas another continued 253 days longer in the larval stage (Table 10).

COMPARATIVE LENGTH OF PERIOD ON DIFFERENT FRUITS

Table 10 is arranged to show the comparative duration of larval life of individuals reared on raisins, prunes, and figs. Despite the smaller number of rearings on prunes and figs, the indications regarding the effect of different fruits are of much interest. Only the first four series are roughly comparable in point of time at which the larvae started life on the different fruits.

TABLE 10.—*Comparison of length of larval life of Indian-meal moth reared on raisins, prunes, and figs, Fresno, Calif., 1925–1927*

Date eggs hatched	Larvae reared on raisins			Date eggs hatched	Larvae reared on prunes			Date eggs hatched	Larvae reared on figs		
	Larvae	Larval life			Larvae	Larval life			Larvae	Larval life	
		Range	Average			Range	Average			Range	Average
1925		*Days*	*Days*	1925		*Days*	*Days*	1925		*Days*	*Days*
Sept. 25–26	114	162–227	183.1	Sept. 26–30	90	163–221	174.3	Sept. 30–Oct. 3	89	157–199	168.0
1926				1926				1926			
Apr. 14–17	20	28– 56	39.9	Apr. 14–16	13	33– 70	47.5	Apr. 16–17	3	25– 41	31.3
June 9	16	21– 61	36.2	June 10–14	20	25– 68	39.4	June 15	11	13– 48	29.5
July 14	22	29– 74	44.1	July 28	4	47– 58	50.8	July 31	2	35– 37	36.0
Do	1	282	282.0	do	3	255–288	266.3				
Aug. 20–21	5	34– 48	40.4								
Do	11	231–267	249.1								
								Sept. 23	1	32	32.0
								Sept. 23–24	15	170–199	186.2
Oct. 16	14	159–188	172.6	Oct. 2	9	172–246	210.4				
								Dec. 1	1	144	144.0

From the rearings begun in the fall of 1925 the longest average larval period (183.1 days) occurred with larvae fed on raisins. On prunes and figs it was 8.8 and 15.1 days shorter, respectively. In the case of the larvae hatched in April, 1926, the average larval period on prunes, 47.5 days, was longest, and those on raisins and figs were 7.6 and 16.2 days less, respectively. Larvae hatched in June also showed the maximum average larval period on prunes, 39.4 days; on raisins the average was 3.2 days less, and on figs 9.9 days less. Again, in the case of larvae hatched in July, the maximum average larval period of 50.8 days was on prunes; on raisins it was 6.7 days less, and on figs 14.8 days less.

The three lots of larvae hatched in April, June, and July, 1926, showed their longest average larval period on prunes, with raisins second, whereas in the case of larvae hatched the preceding fall the maximum was on raisins with prunes second. Thus the evidence that feeding on prunes resulted in slower development is not constant.

In all the comparisons, however, the larvae reared on figs developed more rapidly on the average than those reared on raisins or prunes. The reduction in the average larval period on figs as compared with the longest average period in each series ranged from 9.9 to 16.2 days. The constancy of this tendency offsets in some measure the smaller number of rearings on figs.

Doubtless these variations in larval development are correlated with such differences in the fruits as sugar and moisture content. Levulose and dextrose, in approximately equal parts, predominate in all these fruits, and dried prunes and figs contain small quantities of sucrose in addition to the reducing sugar. The sugar content varies considerably with variety, locality, and method of curing, but among the dried fruits used the fig is highest in sugar content, raisins next, and prunes lowest. The sugar content thus bears an inverse relationship to the length of life of larvae reared on these dried fruits.

The earlier work of Phillips showed that there is no doubt as to the influence of moisture content of food upon larval development. Larvae under observation during the dry season, which were fed upon artificially moistened food, thrived, whereas other individuals, fed upon the same kind of food which was allowed to dry out, either died or developed much more slowly.

The moisture content of each kind of dried fruit is very variable, and it was not determined for the fruit used in the present study. Raisins, however, are ordinarily cured to a lower water content than are prunes and figs; Chace and Church (*3, p. 15*) report that 16 per cent of water is the upper limit at which raisins can be stored without danger of sugaring or molding. Jones and Bullis (*18, p. 5*) state that prunes for best keeping should not have a moisture content in excess of 20 per cent. Like data for the fig are not available. These figures are not pertinent to the larval periods determined in the laboratory, because processed fruit, with somewhat increased moisture, was there used in rearings. Nevertheless, there can be no doubt of the importance of this factor in the larval life of the insect in stored, raw stocks of dried fruits.

THE PREPUPAL STAGE

There is a more or less definite prepupal stage, passed inside the silken cocoon. In early spring it lasts from 0 to 23 days, averaging about 4 days. During the summer the period ranges from 0 to 7 days, with an average of about 1 day. Herms (*15, p. 563*) recorded the duration of the prepupal stage as 9 to 12 days at temperatures ranging from 22° to 26° C.

THE PUPA

DURATION OF THE PUPAL STAGE

Marked variation in the pupal stage in accordance with prevailing temperatures may be noted in Table 11 which is based upon 203 individuals reared on raisins. The means of temperature and relative humidity cover the interval from initial pupation to the last emergence for each group.

TABLE 11.—*Duration of the pupal stage of individuals of the Indian-meal moth reared on raisins, Fresno, Calif., 1926–27*

Date larvae pupated	Pupae	Days of pupal life		Mean temperature [1]	Mean relative humidity [1]
		Range	Average		
1926				° F.	*Per cent*
Mar. 6–31	87	18–33	23.3	69	56
Apr. 1–28	25	7–21	14.4	72	54
May 9–31	18	7–20	10.5	80	42
June 3–30	5	8– 9	8.6	84	39
July 2–28	14	4– 9	7.1	88	39
Aug. 9–29	17	4– 9	6.9	83	42
Sept. 1–28	9	8–16	12.9	74	48
Oct. 3–7	2	12–14	13.0	71	57
1927					
Mar. 24–28	4	29–31	30.0	64	63
Apr. 5–27	18	14–25	19.0	69	55
May 1–14	4	15–18	16.8	72	48
Summary	203	4–33	14.8		

[1] For the period in each group from the initial pupation to the last emergence.

The larvae in Table 11, pupating from March 6 to October 7, 1926, and from March 24 to May 14, 1927, showed as extremes of the pupal period from 4 to 33 days. The shorter periods were during July and August, averaging 7.1 and 6.9 days, respectively. The respective mean temperatures applying to these two groups were 88° and 83° F. The longer pupal periods occurred in the spring with mean temperatures below 70°. Thus, in March, 1927, the average pupal period was 30 days and the mean temperature 64°, whereas in March, 1926, with a mean temperature of 69°, the pupal stage averaged 23.3 days.

The pupal periods of 137 individuals reared on prunes and 112 reared on figs approximated those reared on raisins, except that one prune-fed individual showed a pupal period of 26 days in June.

This range of the pupal period is approximated by records in literature. Popenoe (*21, p. 3*) found that adults emerged as early as 5 days after pupation, and Herms (*15, p. 563*) reported the period as from 24 to 28 days under fluctuating room temperatures of from 15 to 19° C. (59 to 66° F.). On the other hand the 12-day pupal period in the studies of Parker (*20, p. 4*) covering the period from June to August is very much longer for that season than that observed in the present investigation. The same is true of the report of Bioletti (*2, p. 3*) that the pupal stage lasts about 16 days at an average summer temperature of 80° F. Lovett (*19, p. 119*) stated that from 10 to 20 days are passed in the pupal stage.

LENGTH OF LIFE CYCLE

The present study has shown that the life cycle of the Indian-meal moth in the San Joaquin Valley of California is more variable and somewhat longer than is generally indicated in literature. Thus Back and Cotton (*1, p. 16*), Essig (*11, p. 712*), Dietz (*9, p. 84*), and Girault (*13, p. 66*) have indicated that the life cycle is completed in from 4 to 5 weeks. DeOng (*7, p. 241*), having reference to California conditions, states that egg-to-adult development occurs in from 5 to 6 weeks at a temperature of 70° F. or more, and in from 6 to 8 weeks at temperatures below 70°.

Data on the life cycles of 89 individuals from deposition of the egg to emergence of the adult, together with data of temperature and

relative humidity for each such period, are contained in Table 12. These individuals were reared on raisins. Eggs laid from April 4 to 10 produced adults emerging from May 22 to June 21, in 47 to 72 days, the mean egg-to-adult period being 58 days. The mean temperatures for these cycles averaged 76° F. From eggs deposited June 5, adults developed and emerged from July 8 to August 16, the range being 33 to 72 days, and the mean 47.4 days. The average of mean temperatures applying to these individual periods was 85°. Eggs laid July 11 produced mostly transforming individuals, but one was of the wintering type. Adults of the former category emerged August 16 to October 8, ranging from 36 to 89 days and averaging 55.4 days under mean temperatures for the individual periods of from 82 to 88°. The one wintering individual emerged on May 9 the following year, this egg-to-adult period of 302 days being the longest among raisin-fed individuals encountered in the present study. Eggs laid August 17 produced both transforming and wintering individuals. The former emerged from October 7 to 19, with a mean period of 57.6 days and a range of 51 to 63 days, the average of mean temperatures being 77°. The latter emerged from May 1 to June 1 the following year, with a mean egg-to-adult period of 270.1 days. Eggs laid October 10 produced only wintering individuals, emergence occurring the following year from April 24 to May 11, with a mean period of 201.3 days.

TABLE 12.—*Developmental periods of the Indian-meal moth on raisins, Fresno, Calif., 1926–27*

Rearing No.	Date egg was laid	Incubation period	Larval period	Pupal period	Date adult emerged	Interval egg to adult	Sex	Temperature [1]		Mean relative humidity [1]
								Mean	Range, mean minimum to mean maximum	
	1926	*Days*	*Days*	*Days*	*1926*	*Days*		*°F.*	*°F.*	*Per cent*
1	Apr. 4	10	31	7	May 22	48	Male	74	18	53
2	do	10	40	9	June 2	59	do	75	19	51
3	do	10	40	10	June 3	60	do	75	18	51
4	do	10	43	9	June 5	62	do	75	19	50
5	do	10	36	20	June 9	66	do	76	18	50
6	do	10	52	9	June 14	71	Female	76	19	49
7	Apr. 7	10	28	9	May 24	47	Male	74	19	52
8	do	10	34	11	June 1	55	Female	75	20	50
9	Apr. 9	8	37	10	June 3	55	Male	76	20	49
10	do	8	39	8	do	55	Female	76	20	49
11	do	8	39	8	do	55	do	76	20	49
12	do	8	42	9	June 7	59	do	77	20	49
13	do	8	41	10	do	59	Male	77	20	49
14	do	8	49	9	June 14	66	do	77	20	48
15	Apr. 10	7	30	10	May 27	47	do	75	20	50
16	do	7	32	12	May 31	51	do	75	19	50
17	do	7	37	9	June 2	53	do	76	20	49
18	do	7	44	7	June 7	58	Female	77	20	48
19	do	7	47	8	June 11	62	do	77	20	48
20	do	7	56	9	June 21	72	Male	78	20	47
Average	Apr. 4–10	8.5	39.9	9.7		58		76	19	50
21	June 5	4	23	6	July 8	33	Female	84	22	39
22	do	4	21	8	do	33	do	84	22	39
23	do	4	27	4	July 10	35	Male	84	22	40
24	do	4	30	7	July 16	41	do	85	22	40
25	do	4	34	6	July 19	44	Female	85	23	40
26	do	4	33	8	July 20	45	Male	85	22	39
27	do	4	34	8	July 21	46	Female	85	23	39
28	do	4	34	8	do	46	do	85	23	39
29	do	4	35	7	do	46	do	85	23	39
30	do	4	37	6	July 22	47	do	86	23	39

[1] For the interval from deposition of the egg to emergence of the adult.

TABLE 12.—*Developmental periods of the Indian-meal moth on raisins, Fresno, Calif., 1926–27*—Continued

Rearing No.	Date egg was laid	Incubation period	Larval period	Pupal period	Date adult emerged	Interval egg to adult	Sex	Temperature		Mean relative humidity [1]
								Mean	Range, mean minimum to mean maximum	
	1926	*Days*	*Days*	*Days*	*1926*	*Days*		*°F.*	*°F.*	*Per cent*
31	June 5	4	37	7	July 23	48	Female	85	23	39
32	do	4	39	8	July 26	51	Male	86	23	39
33	do	4	40	8	July 27	52	do	86	23	39
34	do	4	45	9	Aug. 2	58	Female	86	23	39
35	do	4	49	8	Aug. 5	61	do	86	23	39
36	do	4	61	7	Aug. 16	72	Male	86	23	39
Average		4	36.2	7.2		47.4		85	23	39
37	July 11	3	29	4	Aug. 16	36	Female	88	24	39
38	do	3	31	6	Aug. 20	40	do	87	24	39
39	do	3	31	6	do	40	Male	87	24	39
40	do	3	30	8	Aug. 21	41	Female	87	24	39
41	do	3	32	8	Aug. 23	43	Male	87	24	39
42	do	3	36	6	Aug. 25	45	do	87	24	39
43	do	3	36	7	Aug. 26	46	Female	87	24	39
44	do	3	39	6	Aug. 28	48	Male	87	23	39
45	do	3	39	6	do	48	do	87	23	39
46	do	3	38	7	do	48	Female	87	23	39
47	do	3	40	5	do	48	Male	87	23	39
48	do	3	37	9	Aug. 29	49	Female	87	23	39
49	do	3	39	8	Aug. 30	50	Male	86	23	40
50	do	3	39	8	do	50	Female	86	23	40
51	do	3	42	9	Sept. 3	54	Male	86	24	40
52	do	3	46	7	Sept. 5	56	do	86	24	40
53	do	3	49	8	Sept. 9	60	Female	85	23	40
54	do	3	60	13	Sept. 25	76	Male	83	23	41
55	do	3	63	13	Sept. 28	79	do	83	24	41
56	do	3	68	14	Oct. 4	85	do	82	23	42
57	do	3	72	13	Oct. 7	88	Female	82	23	43
58	do	3	74	12	Oct. 8	89	do	82	23	43
Average	do	3	44.1	8.3		55.4		86	23	40
					1927					
59	do	3	282	17	May 9	302	Female	66	17	63
					1926					
60	Aug. 17	4	34	13	Oct. 7	51	do	78	23	46
61	do	3	38	14	Oct. 11	55	do	77	22	46
62	do	4	38	16	Oct. 14	58	Male	76	22	47
63	do	3	44	14	Oct. 17	61	Female	76	22	47
64	do	3	48	12	Oct. 19	63	do	76	22	48
Average	do	3.4	40.4	13.8		57.6		77	22	47
					1927					
65	do	3	231	23	May 1	257	Female	63	16	66
66	do	3	240	18	May 5	261	Male	63	17	66
67	do	4	239	18	do	261	Female	63	17	66
68	do	3	246	17	May 10	266	do	63	17	66
69	do	3	247	17	May 11	267	do	63	17	66
70	do	4	248	16	May 12	268	do	63	17	66
71	do	3	250	19	May 16	272	Male	64	17	66
72	do	4	253	15	do	272	do	64	17	66
73	do	3	257	18	May 22	278	Female	64	17	65
74	do	3	262	16	May 25	281	do	64	16	65
75	do	3	267	18	June 1	288	Male	64	17	64
Average	do	3.3	249.1	17.7		270.1		63.5	17	66
76	Oct. 10	6	160	30	Apr. 24	196	Female	59	14	73
77	do	6	159	31	do	196	Male	59	14	73
78	do	6	161	30	Apr. 25	197	do	59	14	73
79	do	6	163	29	Apr. 26	198	Female	59	15	73
80	do	6	172	21	Apr. 27	199	do	59	15	72
81	do	6	173	21	Apr. 28	200	do	59	15	72
82	do	6	172	22	do	200	Male	59	15	72
83	do	6	172	23	Apr. 29	201	Female	59	15	72
84	do	6	171	25	Apr. 30	202	Male	59	15	72
85	do	6	180	17	May 1	203	do	60	15	72
86	do	6	177	20	do	203	do	60	15	72
87	do	6	184	15	May 3	205	Female	60	15	72
88	do	6	185	14	do	205	do	60	15	72
89	do	6	188	19	May 11	213	Male	60	16	71
Average	do	6	172.6	22.6		201.3		59	15	72

The range of the life cycle is broadened slightly by including the rearings on figs and prunes. During the same period in which the minimum of 33 days for raisin rearings was established, two egg-to-adult cycles of 27 days each occurred among the insects reared on figs. During very nearly the same period in which the maximum of 302 days was obtained on raisins, one prune-fed individual required 305 days for egg-to-adult development.

NUMBER OF GENERATIONS PER YEAR

In the rearings reported upon, the generations were kept separate and were begun with eggs laid by the earlier emerged females of the preceding generation. The data thus served to indicate the maximum number of egg-to-adult cycles which may occur during the year. In the case of the first generation the first adult emerged May 22, whereas the first female issued June 1, and a female which emerged

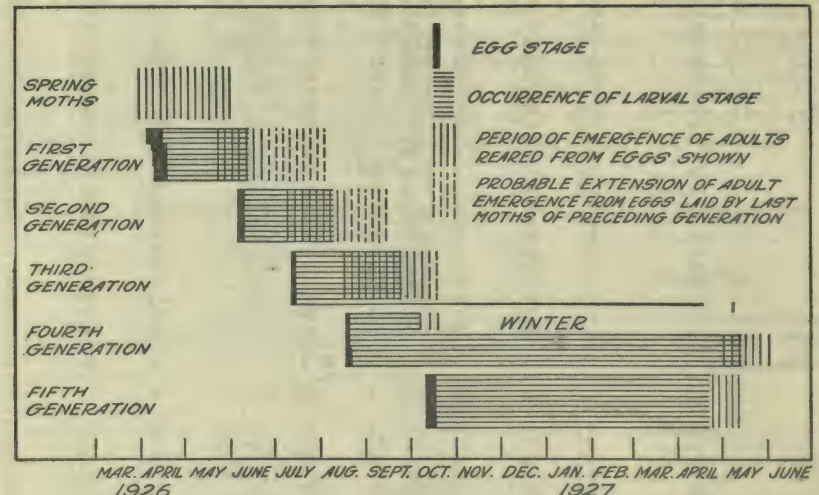

FIGURE 1.—Chart showing generations of the Indian-meal moth reared on raisins in the laboratory from the more advanced females of each generation, and the consequent overlapping of generations

June 3 laid the eggs which produced the second generation. Such delays, however, had no important effect upon the number of generations reared, except in the case of figs.

The relation of the egg stage in each generation to the period of adult issuance in the preceding broods is shown in Figure 1, as is also the occurrence of larvae and emergence of adults actually reared from these eggs. The probable extension of adult emergence which would have resulted from eggs laid by the more retarded moths of the preceding brood is shown for each generation by broken vertical lines.

It may be seen (fig. 1) that all individuals of the first two summer generations completed their development the same year the eggs were laid. Likewise the third generation was very largely completed the same season; only one individual passed the winter in the larval stage and issued as an adult the following year. A small part of the fourth generation emerged during the year of oviposition, but the majority overwintered as larvae and emerged the following year.

All individuals of the fifth generation passed the winter in the larval stage and emerged the next year. There were thus five generations started during the year, composed of two complete and two partial summer generations and the one entirely overwintering generation. Owing to the rearing methods employed these results are indicative of the maximum potentialities of the insect in the San Joaquin Valley when fed on raisins.

Four generations were reared on prunes, beginning with the first spring generation of 1926, as compared with five on raisins and a possible six on figs. Only 33 individuals were reared on figs as compared with 50 on prunes, and besides, all the fig-reared generations except the second were too small in number to permit prompt starting of the succeeding generations. The five generations actually reared upon figs are therefore a less trustworthy index than the six computed from the shortest cycles in each generation.

The vertical lines, both solid and broken, in Figure 1 show the long periods of adult emergence in the several generations and explain the overlapping of generations bred on a single kind of fruit. The tendency to faster development on figs and slower development on prunes would increase this overlapping in packing houses storing all these dried fruits. Furthermore, different rates of development due to varying conditions in different situations in packing houses would result in still further overlapping. Indeed, Figure 1 shows that individuals of three of the segregated generations overwintered and emerged the following spring, so even the spring brood of moths in nature has no common generational status.

PARASITES

Three parasites of the Indian-meal moth have been encountered about dried-fruit packing houses in the San Joaquin Valley. Only one of these, *Habrobracon juglandis* (Ashm.), is abundant. A larger wasp-like insect, *Nemeritis canescens* Grav., is only an occasional parasite. A single female of *Drepanoglossa floridensis* Tns., a small tachinid fly, was collected, and four specimens were reared from Indian-meal moth larvae.

The braconid *Habrobracon juglandis* is often exceedingly abundant about infested stored fruit and destroys very large numbers of Indian-meal moth larvae, but not enough to control the situation without remedial measures. Data obtained in October, 1926, under natural conditions at a packing plant having a very heavy infestation of the Indian-meal moth, serve to emphasize this point.

This particular infestation showed many grown larvae of the Indian-meal moth crawling from sacked dried figs and an abundance of the braconid adults. Many larvae had already been paralyzed by the parasites, and many of them had parasite eggs on them. From a representative area of 40 square feet of the burlap-sack surface, all larvae, except the old, dark-colored, dried-out ones, were collected and placed in individual vials. This collection, including living and recently parasitized larvae, totaled 143. Another collection from 44 square feet of wall and window surface netted 157 larvae. The density of larvae in both cases was 357 per 100 square feet. Of the 143 placed in individual containers, 139 were apparently parasitized and 4 were apparently normal. The four living larvae and one of the apparently dead ones produced moths. Of the remaining 138 larvae, 91

shriveled and died and produced no adult parasites, although many of them supported parasites which did not develop to the adult stage. It is possible either that the parasite eggs were detached from the larvae at the time of collection or that some of them were overparasitized. There is, however, little doubt that their death resulted from the activities of Habrobracon. The other 47 larvae each produced from 1 to 8 Habrobracon adults, the average per larva being 2.5. The estimate of death due to parasitism is thus 96.5 per cent. Notwithstanding this, adults of the Indian-meal moth were exceedingly abundant that fall, and a very abundant larval population overwintered.

Cocoons of *Habrobracon juglandis* are of frequent occurrence inside figs, where, under the pure food law, they constitute contamination just as the original inhabitant would. Taken all in all, this parasite must be considered of no practical value.

SUMMARY

The Indian-meal moth, *Plodia interpunctella* Huebner, originally an Old World pest but now found everywhere, is the most destructive insect attacking stored dried fruits in California, where its presence in packing houses is well-nigh universal. It is a general feeder upon dried vegetable matter, and its cast skins, webbing, and excrement pollute the dried fruits upon the surface of which it feeds. Because of the great quantities of fruit damaged in this way a knowledge of its larval habits, and to a lesser degree its oviposition, incubation, and other activities, are of considerable importance.

This species begins each year with a promiscuous brood of overwintering larvae, some of which date from as early as July and others as late as October of the previous year, and which are the offspring of any generation from the third to the fifth of that year. They pupate mostly in March and emerge as adults in April. As the season proceeds, the blending of generations continues, until eggs, larvae, pupae, and adults of several generations are all present at the same time.

The moths studied in the present instance began ovipositing usually not more than 3 days after emergence and continued ovipositing from 1 to 18 days, the longer periods occurring during the cooler weather of spring and fall. The length of time given to these two activities, especially the lengthy emergence period of the spring brood of moths, resulted in a very considerable extension of the time occupied by the first generation; indeed, adults of the first generation had emerged before the issuance of the last adults of the spring brood. The eggs, which are deposited chiefly at night and attached loosely to the surface of the dried fruit, ranged in number from 39 to 275 for each female, the average for the entire season being 152.3. Moths living in the fall deposited the greatest number, averaging 178.3, as compared with 127.1 during the hot midsummer period, although the oviposition was much faster at the latter time.

In summer, approximately 90 per cent of the eggs were laid during the first three days after mating, instead of during the first 11 as in the spring, and the first 6 in the fall. The eggs may be extruded very rapidly; the greatest number laid in one day was 144, and there is one record of 115 eggs laid in a single hour.

The female moth survived, at the most, only five days after finishing oviposition; and the total term of life, shortest during the hot summer weather, ranged from 2 to 23 days. Males lived from 2 to 25 days.

The blurring of generation lines is much increased by the range of the normal period of incubation from 2 to 14 days, depending directly upon the temperature. The eggs laid in July and August hatched in the shortest time, the average being 3.7 days, whereas those laid by one exceptional female from November 17 to 22 required from 14 to 17 days.

The percentage of hatch, also, though little affected by the heat of summer, was drastically reduced by low temperatures. Thus, of 10,479 eggs deposited from April 4 to October 31, 73.4 per cent hatched, the monthly average ranging from 68.8 to 78.3 per cent as the monthly temperature mean ranged from 68 to 88° F.; whereas of 211 eggs laid exceptionally late in the season and incubated at temperatures averaging 59° F., only 25.1 per cent hatched.

Still more variable than the periods of preoviposition, oviposition, and incubation, and more potent as a cause of confusion, is that of larval development. The shortest individual period was 13 days and the longest 288. Although this extreme range is that of individuals hatched and fed under extremes of environment, and includes, moreover, the semiinactive winter season, it does not greatly exceed that of offspring of a common parent, hatched simultaneously and reared in the same environment, whose larval period ranged from 29 to 282 days. The larval period of individuals, all fed upon raisins, ranged from 21 to 282 days. The inclusion of the winter period is not taking in an exceptional feature, for a small percentage of the larvae which hatched even as early as July, and an increasing proportion of the later ones, remained in the larval stage over winter. Excluding the winter season, however, the shortest average larval period of 36.2 days was established by those hatched in June, and the average larval life of those hatching in July and maturing before winter was longest, being 44.1 days.

Superimposed upon this variation in larval period of individuals, often of common parentage, is an additional variation due to different foods which further confuses the generations. The extreme periods of 13 and 288 days mentioned above were taken from fig-fed and prune-fed larvae, respectively. The average larval period upon figs is shorter than upon raisins or prunes, probably because of the higher sugar and moisture content of figs. Possibly the variations observed in length of life of larvae reared upon a single kind of fruit are attributable to similar differences in the individual fruits.

The pupal period of 203 individuals reared upon raisins ranged from 4 to 33 days, varying inversely with the temperature; and the pupae of those reared upon figs and prunes have approximately the same periods.

The shortest egg-to-adult cycle encountered in this study was 27 days on figs, and the longest, 305 days upon prunes. The cycle of individuals reared on raisins ranged from 33 to 302 days. This resulted in a maximum of five generations in a single year on raisins and four on prunes. More than five probably mature on figs in nature, but in this experiment, although the growth was rapid, the small number of specimens issuing delayed the start and prevented the production of the maximum number of generations.

LITERATURE CITED

(1) BACK, E. A., and COTTON, R. T.
1922. STORED-GRAIN PESTS. U. S. Dept. Agr. Farmers' Bul. 1260, 46 p., illus. (Revised, 1930.)

(2) BIOLETTI, F. T.
1915. CONTROL OF RAISIN INSECTS. Calif. Agr. Expt. Sta. Circ. 134, 11 p., illus.

(3) CHACE, E. M., and CHURCH, C. G.
1927. TESTS OF METHODS FOR THE COMMERCIAL STANDARDIZATION OF RAISINS. U. S. Dept. Agr. Tech. Bul. 1, 24 p., illus.

(4) CHITTENDEN, F. H.
1895. THE MORE IMPORTANT INSECTS INJURIOUS TO STORED GRAIN. U. S. Dept. Agr. Yearbook 1894: 277–294, illus.

(5) ———
1896. INSECTS AFFECTING CEREALS AND OTHER DRY VEGETABLE FOODS. U. S. Dept. Agr., Bur. Ent. Bul. (n. s.) 4: 112–130, illus.

(6) DE ONG, E. R.
1918. DRIED FRUIT INSECTS. Calif. State Comn. Hort. Mo. Bul. 7: 429.

(7) ———
1919. WHAT HINDERS DRIED FRUIT SALES. Calif. State Comn. Hort. Mo. Bul. 8: 240–243, illus.

(8) ———
1921. PREVENTION AND CONTROL OF INSECTS IN DRIED FRUITS. Calif. Dept. Agr. Mo. Bul. 10: 72–74.

(9) DIETZ, H. F.
1914. SOME OF THE MORE IMPORTANT INSECTS AFFECTING GRAINS AND GRAIN PRODUCTS. Ind. State Ent. Ann. Rpt. 6: 79–105, illus.

(10) ESSIG, E. O.
1920. IMPORTANT DRIED FRUIT INSECTS IN CALIFORNIA. Calif. Dept. Agr. Mo. Bul. 9 (sup. 3): 119–124, illus.

(11) ———
1926. INSECTS OF WESTERN NORTH AMERICA . . . 1035 p., illus. New York.

(12) FITCH, A.
1867. REPORTS ON THE NOXIOUS, BENEFICIAL, AND OTHER INSECTS OF THE STATE OF NEW YORK . . . (1856) Rpts. 1 and 2: 1–336, illus.

(13) GIRAULT, A. A.
1912. INSECTS INJURIOUS TO STORED GRAINS AND THEIR GROUND PRODUCTS. Ill. State Ent. Rpt. 27: 56–82, illus.

(14) GREGSON, C. S.
1873. DESCRIPTION OF A LEPIDOPTEROUS INSECT (EPHESTIA ROXBURGHII) NEW TO SCIENCE. Entomologist 6: 318.

(15) HERMS, W. B.
1917. THE INDIAN-MEAL MOTH, PLODIA INTERPUNCTELLA Hubn., IN CANDY AND NOTES ON ITS LIFE HISTORY. (Sci. note) Jour. Econ. Ent. 10: 563.

(16) HÜBNER, J.
1827. SAMMLUNG EUROPAISCHER SCHMETTERLINGE. v. 5, Pyralides, Tortrices, Tineae, Alucitae, illus. Augsburg.

(17) HULST, G. D.
1890. THE PHYCITIDAE OF NORTH AMERICA. Amer. Ent. Soc. Trans. 17: 93–228, illus.

(18) JONES, J. S., and BULLIS, D. E.
1929. THE CHEMICAL COMPOSITION AND FOOD VALUE OF OREGON DRIED PRUNES. Oreg. Agr. Expt. Sta. Bul. 249, 10 p., illus.

(19) LOVETT, A. L.
1921. THE INDIAN-MEAL MOTH (PLODIA INTERPUNCTELLA HUEBN.). Oreg. Bd. Hort. Bien. Rpt. (1919/20) 16: 118–123, illus.

(20) PARKER, W. B.
1915. CONTROL OF DRIED-FRUIT INSECTS IN CALIFORNIA. U. S. Dept. Agr. Bul. 235, 15 p., illus.

(21) POPENOE, C. H.
1911. THE INDIAN-MEAL MOTH AND "WEEVIL-CUT" PEANUTS. U. S. Dept. Agr., Bur. Ent. Circ. 142, 6 p., illus.

(22) [RILEY, C. V., and HOWARD, L. O.]
1889. THE SO-CALLED MEDITERRANEAN FLOUR MOTH. U. S. Dept. Agr., Bur. Ent., Insect Life 2: 166–171, illus.

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27

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TRANSPORTING AND HANDLING MILK IN TANKS

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CONTENTS

	Page
Rapid increase in tank hauling	1
Causes of changes in methods of hauling	1
Object of study	2
Tanks mounted on motor trucks	2
Kinds in use, capacity, and costs	2
Length of routes and speed of hauling	3
Need for supplemental tanks	5
Temperature changes of milk in motor tanks	6
Handling milk from motor tanks at city plants	7
Costs of hauling by tank truck	14
Conditions under which tank-truck hauling is unsatisfactory	16
Tank cars	16
Equipment	16
Length of routes and number of cars required	17
Need for supplemental tanks	18
Handling milk from tank cars at city plants	18
Conditions under which tank-car hauling is unsatisfactory	22
Advantages of hauling milk in tanks as compared with hauling milk in cans	23

RAPID INCREASE IN TANK HAULING

Adequate facilities for transporting milk are necessary in extending the area of a milk shed. Not only must the means of transportation be regular, but it must be quick and sanitary in order to deliver the product in the city with the least possible lowering in quality. No system yet devised has fulfilled the above requirements to the same extent as have the tank car and tank truck. The year 1910 saw the first tank car and 1914 the first tank on motor truck for use in the transportation of milk. Since then the use of tanks has increased rapidly until at present some cities receive 70 to 95 per cent of their fluid milk in tanks.

CAUSES OF CHANGES IN METHODS OF HAULING

To what may the increase in the use of tanks be attributed? The building of good roads has made it possible for motor vehicles to go into nearly every farming section in the country; and also, the motor vehicle itself has been greatly improved. Furthermore, in some cities, because of their rapid growth and their milk-ordinance requirements, dealers have been compelled to obtain part of their milk supplies from outlying territories; and in their endeavor to maintain quality, price, and ease of shipment they have turned to tank hauling. For example, in Chicago the city board of health passed a regulation requiring that all milk entering the city be from tuberculin-tested

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cows. There were not enough tuberculin-tested cows in the Chicago milk territory to supply the city with milk at the time the law went into force, for the following reasons: (1) A lack of funds for indemnifying owners for condemned tubercular cows, (2) the physical impossibility of testing the necessary number of cows within the time limit, and (3) the feeling on the part of some producers that the law would not be enforced. Dealers, therefore, were forced to go beyond the former limits of their milk territory. As a result, tank shipment of milk into Chicago increased 21 per cent from December, 1925, to May, 1926. For another example note Detroit. The rapid growth of this city has changed what were formerly good dairy-production sections into suburbs or market gardens, and milk dealers have been forced to go farther away from the city for their supplies.

OBJECT OF STUDY

The object of the study reported in this bulletin was to determine the methods of handling milk delivered to the plant in tanks, the labor and time requirements of tank delivery, the advantages and dis-

FIGURE 1.—A semitrailer, equipped with air brakes, on which a 2,000-gallon milk tank is mounted

advantages of such delivery, and the cost of handling milk in this way. Data on 300 tank trucks, 89 trailers, and 53 tank cars were collected by the bureau in 1927–1929; and observations were made on 82 tank trucks, 29 tank trailers, and 28 tank cars.

TANKS MOUNTED ON MOTOR TRUCKS

KINDS IN USE, CAPACITY, AND COSTS

Data collected on 438 tanks showed the following kinds of tanks in use, in the percentages given: Glass-lined steel, 84 per cent; tin-lined copper, 9 per cent; nickel, 6 per cent; and stainless steel, 1 per cent. The last-mentioned type is the latest to be put on the market. Of these tanks, 82 per cent were insulated. The insulating materials were cork, wood, felt, and canvas pads, given in order of frequency of use. In 87 per cent of the insulated tanks, cork approximately 2 inches thick was used, which was protected by heavy canvas, sheet aluminum, or sheet steel. Either aluminum or sheet steel is to be preferred, as they have a smoother surface, are easier to clean, and protect the cork better than the canvas.

The type of chassis upon which a tank is mounted depends upon the capacity of the tank and the road laws of the State in which the tank is used. Most tanks up to 1,250 gallons capacity are mounted on regular motor chassis. Where the load to be carried is larger than this, the tank usually is mounted on a semitrailer (fig.1); or in some cases two medium-sized tanks of 1,000 to 1,250 gallon capacity each are mounted on a 6-wheel chassis.

The capacity of 252 tanks studied ranged from 500 to 2,000 gallons. Seventy-two per cent were of 1,000 to 1,400 gallons capacity, approximately one-third being between 1,000 and 1,100 gallons. The 2,000-gallon tanks were used on semitrailer chassis. Tanks used on trailers did not vary in capacity so much as did those used on trucks, the capacity of the former ranging between 1,050 and 1,100 gallons.

The cost of 70 tanks mounted on motor trucks was obtained. Forty of these tank-trucks, or 57 per cent, cost $6,000 to $8,500 each; 17 or 24 per cent, cost $6,000 to $6,500 each. The average cost was $5,994, and the range was from $2,500 to $9,762, the lower costs being those of small outfits and used equipment. The average cost per gallon capacity was $5.17.

LENGTH OF ROUTES AND SPEED OF HAULING

The consensus of opinion of tank-truck owners and operators is that the economical limit of tank-truck hauling is from 120 to 150 miles per round trip, depending upon the type of roads and topography of the country. Table 1 divides 92 of the routes into 25-mile zones and shows the time en route and the miles per hour for each route within these zones. The length of 79 motor-tank routes out of 113 studied, or 70 per cent, was between 29 and 111 miles round trip.

The distance traveled per hour for the 0 to 25 mile zone was 15.8 miles per hour; for the 25 to 50 mile zone, 15.9 miles per hour; for the 50 to 75 mile zone, 17.2 miles per hour; for the 75 to 100 mile zone, 18.5 miles per hour; and for the 100 to 125 mile zone, 17.3 miles per hour. The decreased average in distance traveled per hour for hauls over 100 miles in length was caused by the fact that the drivers made more stops for gasoline and oil, passed through more towns, and required a lunch period.

TABLE 1.—*Effect of length of route on distance traveled per hour by tanks mounted on motor trucks*

0 TO 25 MILE ZONE

Length of route (miles)	Time en route	Distance traveled per hour	Length of route (miles)	Time en route	Distance traveled per hour	Length of route (miles)	Time en route	Distance traveled per hour
	H. m.	*Miles*		*H. m.*	*Miles*		*H. m.*	*Miles*
2	8	15	10	25	24	20	1 30	13
3	20	9	11	45	15	20	1 30	13
3	15	12	11	38	17	20	1 30	13
3	15	12	12	50	14	20	1 30	13
7	30	14	12	38	19	20	1 0	20
8	30	16	14	45	19	20	1 30	13
10	35	17	15	40	23	20	2 0	10
10	35	17	15	60	15	22	1 15	18
10	45	13	18	1 30	12	24	55	26
10	25	24	18	1 30	12			

25 TO 50 MILE ZONE

25	1 30	17	31	2 15	14	42	2 30	17
25	1 30	17	34	3 0	11	42	2 0	21
25	1 0	25	35	2 15	16	44	2 20	19
27	2 30	11	35	2 0	18	45	3 0	15
28	2 0	14	36	2 30	14	45	3 0	15
30	2 0	15	39	3 0	13	45	2 30	18
30	2 0	15	40	2 30	16			

50 TO 75 MILE ZONE

50	4 0	13	52	3 0	17	66	4 0	17
50	3 30	14	53	3 0	18	67	4 0	17
50	3 20	15	54	3 30	15	70	5 0	14
50	3 0	17	55	3 0	18	70	2 45	25
50	2 0	25	58	2 45	21	72	4 0	18
50	3 0	17	60	4 0	15	72	6 30	11
50	2 40	19	65	4 0	16	73	5 30	13
51	2 15	23	65	4 0	16			
52	3 0	17	65	3 0	22			

75 TO 100 MILE ZONE

75	4 0	19	80	4 0	20	90	6 0	15
80	4 0	20	85	6 0	14	90	6 0	15
80	4 30	18	85	5 30	15	94	4 0	24
80	4 0	20	88	3 45	23			

100 TO 125 MILE ZONE

100	7 0	14	110	10 0	11	125	7 0	18
100	6 30	15	110	6 30	17			
100	4 15	23	120	5 0	24			

Plants operating large numbers of tank trucks should have some method of obtaining information concerning the length of routes, time en route, attention given to trucks, their performance, loads carried, etc. This is all the more important if the daily supply of milk depends entirely upon this means of transportation. The usual method of obtaining information is by a driver's report card, one form of which is shown here:

Driver's Daily Report Card

Date _____, 193____
Truck No. _____ Station _____
Trailer No. _____ Station _____
Daily mileage _____
Gallons gasoline received _____
Engine oil received _____
Truck lubricated _____ Yes _____ No _____
Time leaving station _____
Idle time on road _____
Cause _____
Time arriving _____
Unloading hours _____
Time leaving _____
Idle time on road _____
Time arriving at station _____
Weight of milk on truck _____
Weight of milk on trailer _____
Weight of milk on trailer _____
Is truck running OK? _____
If not, what is wrong? _____
_____
_____
Weather: Fair _____ Rain _____ Snow _____
Roads: Good _____ Rough _____ Muddy _____
Signed _____
Driver.

This card is solely a route report. Some cards combine with this a station report giving quantity of milk of various grades received, time of receiving last shipment, quantity of milk carried over, and other facts which the main plant must know.

NEED FOR SUPPLEMENTAL TANKS

The frequency with which tank trucks need repair and overhauling depends on the length of routes, contour of the roads, type of driver, and size of load. A partial load puts an extra strain on the chassis and motors because of the surge of the liquid contents. Therefore, extra tanks should be kept not only to replace the regular equipment when it is broken down or the motor overhauled but also to haul surplus milk and to meet the requirements of road laws.

For example, during March, April, and May of each year one State requires that the maximum axle load carried on concrete pavements or pavements with concrete base, for trucks with spacing of axles of 9 feet or over, shall not exceed 13,500 pounds, that the maximum load on any wheel shall not exceed 450 pounds per inch of width of tire if axle spacing is under 9 feet, and that the maximum load for any wheel shall not exceed 525 pounds per inch of width of tire; for all other types of road, the maximum axle load with spacing of 9 feet between axles shall not exceed 10,000 pounds, and the maximum wheel load at any axle spacing shall not exceed 450 pounds per inch of width of tire.

Another State has a law applying to weights and speeds in times of thaws and excessive moisture. This law permits the director of highways to prescribe a reduction in carrying weight of not more than 25 per cent on State highways, and of not more than 50 per cent on other highways.

Laws of this nature limit the load of motor trucks to within 15 to 50 per cent of capacity, depending upon size of truck, type and size of tires, and kind of roads, and the difference between what the truck

could haul and what it is permitted to haul, must be carried with extra equipment.

Most plants operating only one or two trucks usually would find it uneconomical to have extra equipment to take care of emergencies. What is considered the economical point at which such equipment is feasible? Most of the tank owners and operators interviewed agreed that a milk plant should have at least four regular routes, depending somewhat upon the length of the routes. However, it is not necessary to have all the extra tanks motorized; most of them may be mounted on trailers.

TEMPERATURE CHANGES OF MILK IN MOTOR TANKS

Table 2 shows the effect of time en route upon variation in temperature of milk hauled in insulated full tanks, as reported by tank owners and operators throughout the country. This table shows a great uniformity in temperature changes of the milk, for within the air-temperature range of 40° to 100° F., 63 per cent reported a rise of only 2° to 3°. Much of the rise in temperature, however, may have been due to the temperature of the tank when the milk was put into it. The temperature of a tank will be about that of the atmosphere unless means are provided for precooling the tank.

TABLE 2.—*Effect of air temperature and time en route upon change in temperature of milk hauled in 43 insulated tanks*

Air temperature and time en route	Change in temperature	Air temperature and time en route	Change in temperature	Air temperature and time en route	Change in temperature
0° to 39.9° F.		70° to 100° F.		70° to 100° F.	
H. m.	°*F.*	*H. m.*	°*F.*	*H. m.*	°*F.*
3 0	0	0 20	0	2 30	+2.0
3 0	−3	0 45	+1.0	3 0	+5.0
4 0	0	1 0	+1.0	3 0	+2.0
4 0	0	1 0	+1.0	3 20	+2.0
6 0	0	1 0	+0.5	4 0	+1.0
		1 30	+2.0	4 0	+2.0
40° to 69.9° F.		1 30	+2.0	4 0	+1.5
		1 30	+1.5	4 0	+3.0
		1 35	+2.0	5 0	+2.0
1 0	−1.0	2 0	+2.5	5 30	+3.0
1 30	+2.0	2 0	+2.0	6 0	+3.0
2 45	+2.0	2 0	+0.5	6 0	+2.0
3 0	+2.0	2 0	+1.0	7 0	+4.0
3 30	+2.0	2 0	0	8 30	+2.0
4 0	+1.5	2 15	+4.0	10 0	+4.0
6 30	+2.0	2 30	+1.0		

At one plant observations were made on two occasions of the temperature of milk hauled in a 2-inch cork-insulated tank and in an uninsulated tank of the same size, loaded at the same country plant with milk of the same temperature. The length of the haul was 55 miles, the trip was made in approximately 4 hours, and the air temperature ranged between 73° and 83°F. During the trip the milk in the uninsulated tank rose 12.6° in temperature more than the milk in the insulated tank. This illustrates the importance of insulating the tanks.

HANDLING MILK FROM MOTOR TANKS AT CITY PLANTS

In handling milk delivered by tank trucks at city plants, three steps are involved: (1) Preparation for unloading, which includes getting the truck in position for unloading, stirring the milk, connecting pipes, taking samples, and opening valves; (2) unloading and weighing the milk; and (3) washing the tank, which also includes disconnecting pipes and closing all openings, and treating it to kill bacteria. Table 3 shows the number of man-minutes required per 1,000 gallons of milk and the percentage of the total time used for each of these operations at 15 plants.

TABLE 3.—*Labor required for each step in handling milk from motor tanks at 15 city plants*

Plant No.	Preparation for unloading		Unloading and weighing		Washing tank and treating to kill bacteria	
	Man-minutes per 1,000 gallons	Per cent of total labor	Man-minutes per 1,000 gallons	Per cent of total labor	Man-minutes per 1,000 gallons	Per cent of total labor
1	5.0	13.8	16.8	45.9	14.7	40.3
2	12.4	31.7	17.8	45.7	8.8	22.6
3	6.0	11.3	25.6	48.0	21.7	40.7
4	7.8	11.6	40.3	59.9	19.3	28.5
5	10.8	20.7	31.8	55.8	12.2	23.5
6	5.1	17.2	18.1	60.2	6.8	22.6
7	2.5	3.8	25.0	38.1	38.1	58.1
8	2.7	4.5	30.6	50.0	27.2	45.5
9	4.4	8.5	28.2	53.9	19.6	37.6
10	2.7	6.1	33.2	74.5	8.6	19.4
11	8.5	15.0	29.3	51.9	18.7	33.1
12	5.5	10.2	35.1	64.9	13.5	24.9
13	7.1	12.6	39.1	69.4	10.1	18.0
14	10.9	14.1	44.9	57.7	21.8	28.2
15	5.9	13.3	30.2	67.9	8.4	18.8
Average	6.5		29.7		16.6	

In only four plants was the labor of unloading and weighing less than 50 per cent of the total labor. Plants 7 and 8 were the only ones using steam for treating to kill bateria. Of the 38.1 and 27.2 man-minutes per 1,000 gallons used for washing and treating in these two plants, 12.5 and 10.6 man-minutes were used for steaming.

PREPARATION FOR UNLOADING

In getting the truck into position for unloading, it is driven or backed to the unloading place and the front raised to such an angle as to make certain that all milk will pass through the outlet. The general practice is to drive the front wheels onto wedge-shaped pieces of timber from 6 to 8 inches thick. Few plants back their trucks to the unloading position, as it takes extra time and requires more area for maneuvering the trucks, especially semitrailers. Where facilities are available for unloading more than one tank at the same time (Fig. 2), backing saves extra lengths of pipe. The unloading space illustrated in Figure 2 is fully protected from the weather by being inclosed within the plant.

Forty-seven per cent of the plants observed used some means of stirring the milk, either the electric stirrer, a stirrer propelled by chassis motor, a hand stirrer, or compressed air. The electric stir-

rer is either separate or attached permanently to the tank. If it is separate, the manhole must be opened completely and the stirrer either be fastened to the edge of the opening or be held by hand. This thoroughly agitates the milk. However, it is likely to injure the glass lining around the neck of the tank; to add bacteria from the stirrer itself because of carelessness in handling; and it leaves the milk exposed to atmospheric contamination.

Stirrers permanently connected to the tank and run by either separate electric motor or special attachments from the motor of the truck, are very satisfactory. Care must be taken to see that the packing box of the shaft is kept tight and clean.

Hand stirrers are subject to the same criticism as the separate electric stirrers. In addition, there is danger that stirring will not be continued long enough to agitate the contents of the tank thoroughly.

Compressed air was used the least. The general criticisms of this means are that the air must be filtered thoroughly and that the

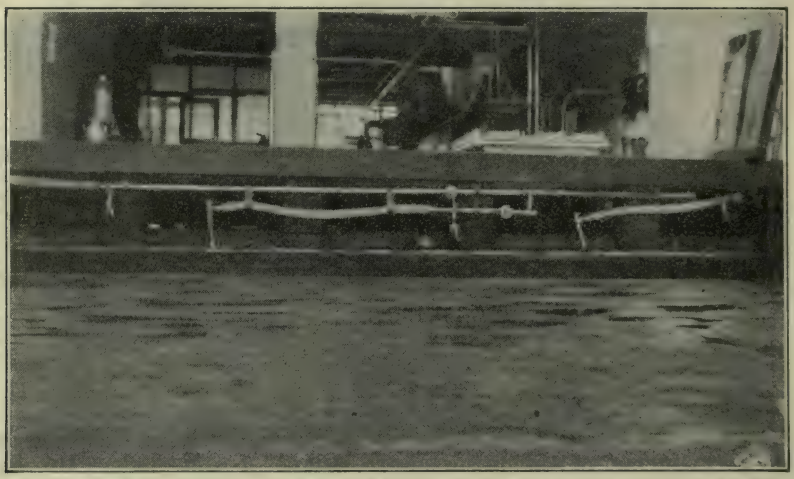

FIGURE 2.—Battery system for unloading tank trucks. Entire floor space is protected by building

small-sized pipe which is placed in the milk is hard to clean and therefore often neglected. However, in using compressed air there is very little chance of atmospheric contamination, as only a small opening into the tank is necessary. Furthermore, the stirrer does not injure the neck of the tank.

The opening to the outlet valve should be flushed with pure water before the pipe for emptying the milk from the tank is attached, as this opening, when not protected by a cap, collects mud and road dust. Even if the opening is protected by a cap, milk may leak through the valve and accumulate in the cap. This milk will be warmed to atmospheric temperature, bacteria will multiply rapidly, and if the milk is not rinsed out it may be a source of contamination. The valve is sometimes placed in a position hard to reach. (Fig. 3.) A valve so placed that the operator must crawl under the chassis is seldom taken apart for washing. It is very important that the valve be placed where it is easily accessible for attaching the pipe and for taking it apart to clean. (Fig. 4.)

Connections from the tank to the plant are made by straight sanitary pipe, flexible copper pipe, or rubber hose. Of these three, the

rubber hose is in most general use, as it is flexible enough to be easily attached and it wears well. It is usually of the best material obtainable, white in color, and may or may not be reenforced between the layers with heavy wire. Care must be exercised to keep it clean and sanitary. The straight sanitary pipe is the easiest to keep clean and

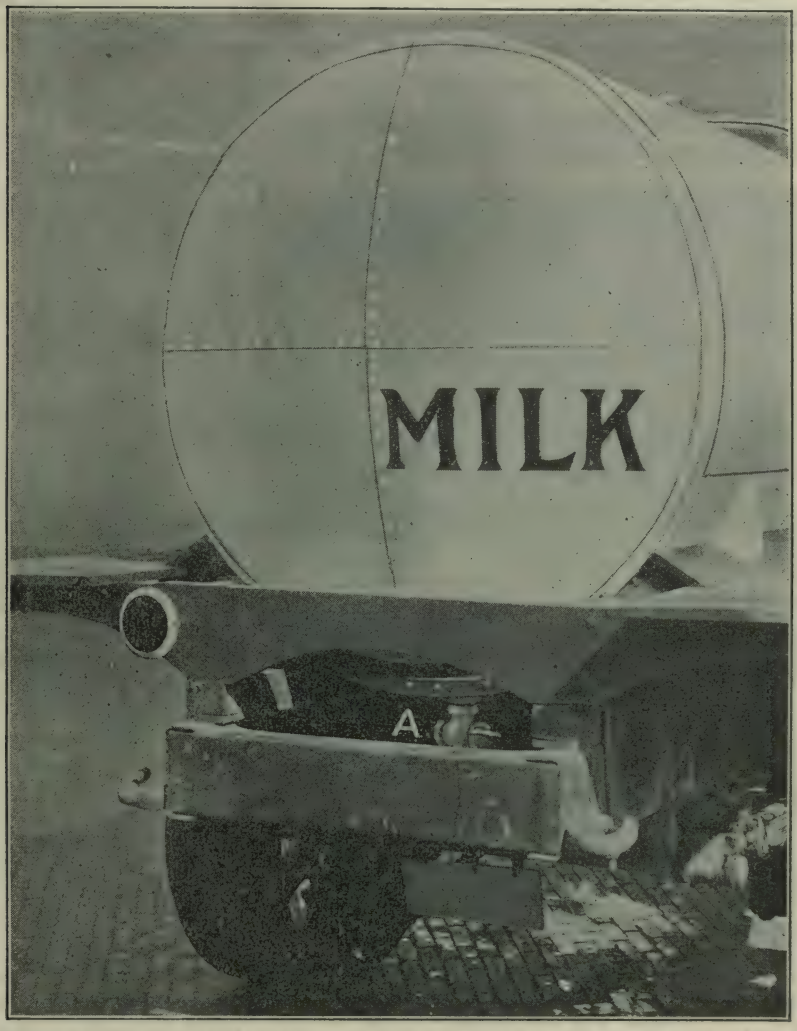

FIGURE 3.—The valve (A) on this milk-tank truck is difficult to reach for cleaning and unloading

comparatively free from bacteria, but it has the disadvantage that unless the truck is placed in a certain position the pipe is difficult to attach and the joints are hard to tighten so as to prevent leakage. From 6 to 10 feet of flexible copper tubing and rubber hose are used to connect the tank with the sanitary piping. The flexible metal tubing is easy to clean and treat to kill bacteria, but it jams easily; even a slight jam causes it to leak.

It is customary to take samples for butterfat tests and bacterial counts directly from the tank. This is one reason why thorough stirring is necessary. In taking both samples the bottles are let down into the milk through the manhole, a sterile container being used for the bacteria sample. At some plants when the milk is unloaded into a single container the butterfat sample is taken from it after the milk has been thoroughly agitated. However, at all plants bacterial samples should be taken directly from the tank.

WEIGHING AND UNLOADING

As tank trucks carry comparatively large loads of milk in bulk, they require a different system for checking weights at the receiving end than do other methods of hauling. The larger the percentage of total milk received in tanks, the greater is the necessity for checking the weights. If only 5 per cent of the total milk is hauled in tanks, errors in estimating this quantity make very little difference when spread over the whole, but if 90 per cent is received in tanks the error in estimating would be of considerable importance to the plant. Sixty per cent of the plants observed used some system of weighing. Three methods of weighing were used: The platform, 2-hopper scales, and 1-hopper scales.

FIGURE 4.—The valve on this milk-tank truck is in an accessible position. Dust cap has been removed

Platform scales have some disadvantages. The possibility of error is large, and they are hard to keep in adjustment. Then, too, there is a tendency to neglect weighing the tare every day. This in itself makes for large errors, as the weight of the truck varies with the moisture in the air, the amount of dust and mud on the truck, the amount of gas and oil in it, and the extraneous material which may be carried.

The 2-hopper scales are in general use. Errors in weight are likely to occur, as most hoppers hold only 1,000 pounds each, and 10 to 12 weighings of each tank must be made. At times the operator may forget to set down one weighing. Then, too, the scales are hard to

balance when each hopper is emptied. Some plants overcome this difficulty by installing a weigh scale for each hopper.

The 1-hopper scales are used in few plants, on account of the expense and extra room required for installation. However, as the hopper is large enough to accommodate the contents of any tank, accurate weights can be made if the scales are sensitive and care is used to keep them in adjustment. Accurate samples for butterfat testing can be taken without the necessity of opening, stirring, and exposing the milk to the outside atmosphere.

Weighing the milk and unloading it from tank trucks require nearly as many man-minutes of labor as do all the other operations. In the 15 plants represented in Table 3 these two operations averaged 56.2 per cent of the total labor. (See p. 7.)

Milk is unloaded from tanks by gravity, pump, or compressed air. Of 80 plants for which reports were received and observations made, 48.7 per cent unloaded by pump, 38.8 per cent by gravity, and 12.5 per cent by compressed air. The air pressure used varied between 10 and 16 pounds, most plants using 10 to 12 pounds. When gravity is used, some means must be provided for elevating the milk to the upper floors of the plant. Observations at 17 plants showed the average number of gallons unloaded per man-minute by the different systems to be as follows: Gravity, 19.12; pump, 20.54; and compressed air, 25.91. Disregarding the number of men, the number of gallons unloaded per minute was as follows: Gravity, 46.4; pump, 65.2; and compressed air, 89.5. Rates for the above systems may vary from those indicated, depending upon size of pipe, size and capacity of pump, and air pressure used. For example, at one plant equipped with compressed air, all tanks but two were unloaded at the rate of 101 gallons a minute through a 3-inch pipe line with an air pressure of 10 to 12 pounds. The other two tanks, which had a 2-inch opening, were unloaded at the rate of 80.5 gallons a minute. If the plant is so arranged that a gravity system can be used, a small number of tanks can be unloaded satisfactorily. However, if the plant uses a large number of tank trucks, the rapidity of receiving is an important factor, and if the arrangement is unsatisfactory for gravity one of the other systems of unloading is preferable.

WASHING AND TREATING TO KILL BACTERIA

Washing the tanks and treating them to kill bacteria are of prime importance. The tanks not only must be clean, but they must also be comparatively free from odors and bacteria. On an average, milk tanks are more carelessly cleansed than the other equipment of the plant. Tanks were inspected for cleanliness by plant men at 52 per cent of the plants studied. Of these, 16 per cent inspected the tanks each day immediately after washing, 28 per cent inspected them twice weekly, and 8 per cent asked for inspection at country plants. At 56 per cent of the plants observed the tanks were washed without being moved from the unloading place; at 28 per cent they were washed in the garage, which was usually some distance from the plant; and at 16 per cent they were moved short distances.

The following form shows a report on tank washing at the city plant, tank inspection and filling at the country station, and condition of the milk upon arrival at the city plant, which the manager of one city plant required to be filled out with every shipment.

Tank Wash Report

Truck tank No. _____ Trailer tank No. _____

Washed by _____

Date _____ Time _____ {A. M. / P. M.

Tank Inspection, Trip, Grade, and Stock Report

Station _____ Date _____

☐ Tank clean. ☐ Tank not clean.
☐ Tank sweet. ☐ Tank odorous.
☐ Valve clean. ☐ Valve not clean.

Remarks: _____

Driver's name _____

Station arrival _____ {A. M. / P. M.

Station departure _____ {A. M. / P. M.

Grade ☐ ☐ Temp. _____ ° F.

Approximate milk on hand after this shipment, including to-day's receipts:

_____ cans. _____ cans.

Signed _____
Station Manager.

Arrival _____ {A. M. / P. M.

Temp. _____ ° F. Quality:

_____

_____

Table 4 gives data on washing tanks and treating them for bacteria at 17 plants. When the driver of a tank was on hand his time was included, as he assisted in turning on water, taking apart and assembling valves, and taking care of tools used in washing. The capacity of the tank had no direct bearing upon the amount of labor required to wash it, as the labor varied from 6.8 to 27.7 man-minutes per 1,000 gallons. The man-minutes per tank ranged from 7.4 to 36, a variation of 386 per cent, with an average of 17.6 man-minutes.

There was no uniformity in the temperature of the wash water used at different plants. A difference of 65° F. was found between plants and of 57° at different times in the same plant. At no plant was a thermometer used to gage the temperature of the water. Twenty-nine per cent of the plants changed the temperature of the water for rinsing. Eleven plants used some form of cleansing powder, and two used vegetable-oil soap. There was no uniformity in the amount of powder used; the amount varied from ½ to 5¼ pounds per tank. There is no reason why tanks on trucks should require any more cleansing powder per 1,000 gallons capacity than other milk equipment within the plant.

TABLE 4.—*Time and materials employed in washing tanks mounted on trucks and treating them to kill bacteria at 17 plants*

Plant No.	Average time per tank		Range in time per tank	Average time per 1,000 gallons of milk	Average percentage of total man-minutes used for washing and treating	Average temperature of—		Range of temperature of wash water	Washing powder used	Chlorine used per tank for each washing
						Wash water	Rinse water			
	Man-minutes	*Minutes*	*Man-minutes*	*Man-minutes*	*Per cent*	*°F.*	*°F.*	*°F.*	*Pounds*	*Pints*
1	9.4	8.9	6–20	6.8	22.6	67	--------	63–70	1.15	--------
2	8.2	8.2	7–10	8.4	18.8	92	163	90–95	5.25	--------
3	7.7	4.5	4–14	8.5	19.4	125	--------	120–129	--------	--------
4	15.7	15.4	3–32	8.8	22.6	107	--------	81–131	[1] 0.50	--------
5	7.4	6.3	5–10	10.2	18.0	82	--------	77–86	[2]	1
6	15.5	7.9	9–28	12.2	23.5	132	--------	90–147	--------	4
7	8.7	10.0	10–22	12.6	24.4	104	--------	99–115	0.62	3
8	10.4	7.0	5–16	13.5	24.9	114	--------	77–122	2.56	1
9	28.1	16.3	13–40	14.7	40.3	129	--------	109–149	1.50	4
10	19.1	9.6	10–34	18.7	33.1	106	--------	77–131	0.62	[4]
11	24.7	12.3	18–34	19.3	[3] 28.5	84	190	185–194	0.87	1
12	19.2	11.1	8–34	21.4	28.2	77	--------	68–90	--------	--------
13	28.2	14.5	20–38	21.7	40.7	101	--------	93–109	0.85	1
14	20.3	20.3	27–34	24.6	[5] 47.3	107	164	104–109	4.25	--------
15	22.5	22.5	15–30	27.7	[6] 45.0	78	147	131–185	--------	--------
16	36.0	18.0	30–42	--------	--------	[7]	--------	--------	[8]	--------
17	--------	--------	--------	--------	--------	104	162	--------	[9]	--------
Average	17.6	12.1	--------	15.3	--------	100.6	165	--------	1.82	2.14

[1] Twice weekly.
[2] Saturated solution of washing powder brushed over tanks twice weekly.
[3] Steam turned into each tank for 1 minute.
[4] Chlorine mixed with washing powder at the rate of 1.5 pounds of chlorine to 5 pounds of powder.
[5] 15.5 per cent of total man-minutes used for steaming.
[6] 17.5 per cent of total man-minutes used for steaming.
[7] Air gun used to force water.
[8] Vegetable-oil soap used; 8 pounds to 50 gallons of water; 1½ gallons of mixture used per tank.
[9] 1 pound of vegetable-oil soap mixed with 2 gallons of water; entire amount used for each tank.

Very few plants used either steam or chemicals in treating their tanks to kill bacteria. Forty-seven per cent used some form of chlorine, but most of them used it only as a deodorizer. The usual method at the plants observed was to pour a pint or more of chlorine solution (the solutions used being of various strengths) into the tank and let it drain out, so that it came in contact with only the drain water along the bottom; some partly filled their tanks with water, poured the chlorine solution in, and let the treated water swash around until the return trip was nearly completed, when it was drained out; a few brushed the chlorine over the inner surface of the tanks. Chemicals, when used properly, are very satisfactory in killing bacteria, but should be applied with a sprayer so as to reach every part of the tank. Only three plants used steam; in two of these 18 to 19 per cent of the total time used for cleansing was used in applying the steam, which would be a considerable item in plants operating large numbers of trucks. Insulated tanks treated with steam cool slowly, a fact which adds another difficulty if they are to be used within a few hours.

Equipment used for washing and treating was found to consist of rubber hose, brushes, sponges, rags, and sprayers. Rubber hose, brushes (one type for the openings and one for the tank), and sprayers are essential. Sponges and rags should have no place in cleansing milk equipment. The rubber hose should be kept on an automatic reel so that it does not touch the ground, and its use should be restricted to cleaning the tank.

COSTS OF HAULING BY TANK TRUCK

The costs of tank-truck hauling can be grouped under the following heads: Depreciation; gasoline, oil, and tires; parts and repairs, including mechanic's wages; labor, including the proportional share of superintendence; interest, if the policy of the company includes interest in its cost account; and miscellaneous expenses, which may cover license, insurance, housing cost, claims for losses, road expense, or items not classified above. Table 5 shows the hauling cost per hundredweight mile and per 100 pounds at 15 plants. The total cost per hundredweight mile varied from $0.0017 to $0.0049, with an average of $0.00273 per plant. Nine of the plants used trailers. The average cost of hauling at these plants was $0.0028 per hundredweight mile, and at the other plants $0.0034.

TABLE 5.—*Cost per hundredweight mile and per 100 pounds for hauling with tank trucks at 15 plants*

Plant No.	Depreciation		Gasoline, oil, and tires		Repairs		Labor for operation	
	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total
1	$0.00071	26.2	$0.00061	22.4	$0.00024	9.1	$0.00091	33.6
2	.00065	10.4	.00096	26.3	.00083	23.5	.00100	31.4
3	.00063	33.4	.00064	33.9	.00010	5.5	.00032	16.7
4	.00120	25.0	.00180	36.4	.00043	8.6	.00150	30.0
5	.00047	15.8	.00090	30.4	.00043	14.6	.00086	29.2
6	.00077	27.9	.00075	27.6	.00012	4.3	.00073	26.7
7	.00042	15.7	.00118	43.9	.00016	5.8	.00080	29.8
8	.00030	18.4	.00060	36.3	.00013	8.0	.00042	25.1
9	.00050	18.5	.00100	37.0	.00008	3.1	.00096	36.9
10	.00027	12.6	.00069	32.8	.00051	24.4	.00049	23.5
11	.00066	21.9	.00096	32.0	.00014	4.4	.00096	31.9
12	.00034	12.3	.00110	39.9	.00007	2.4	.00101	36.9
13	.00087	25.9	.00119	35.2	.00018	5.5	.00100	29.8
14	.00025	13.2	.00043	22.8	.00041	21.6	.00066	34.6
15	.00030	15.5	.00041	21.1	.00050	25.5	.00055	28.1

Plant No.	Interest		Miscellaneous		Total		Distance hauled	Contour and type of roads
	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total	Per hundredweight mile	Per 100 pounds		
							Miles	
1	----------	------	$0.00023	8.7	[2] $0.0027	$0.324	119	Slightly rolling; mostly concrete, with some gravel.
2	$0.00015	4.2	.00018	4.2	.0038	.289	77	Very hilly and bad curves; concrete and macadam.
3	----------	------	.00020	10.5	[2] .0019	.179	94	Rolling; concrete and macadam.
4	([1])	------	----------	------	.0049	.140	28	Some hills; gravel and concrete.
5	.00015	5.1	.00014	4.9	[2] .0029	.266	90	Slightly rolling; mostly concrete.
6	.00025	9.3	.00001	4.2	[2] .0026	.143	52	Level; cement.
7	.00008	2.9	.00005	1.9	[2] .0027	.268	100	Slightly rolling; part gravel; remainder concrete.
8	.00010	5.6	.00011	6.6	[2] .0017	.179	108	Slightly rolling; gravel and concrete.
9	.00017	4.5	----------	------	.0027	.065	24	Hilly; gravel.
10	.00006	2.7	.00008	4.0	[2] .0021	.075	36	Rolling; concrete and macadam.
11	.00014	4.4	.00016	5.4	.0030	.151	50	Level; concrete and macadam.
12	.00019	7.1	.00003	1.4	.0027	.131	48	Rolling; concrete.
13	.00013	3.7	.00002	.4	.0034	.068	20	Do
14	.00007	3.9	.00007	3.9	[2] .0019	.149	78	
15	.00006	3.0	.00014	6.8	[2] .0020	.173	88	

[1] Included in depreciation.

[2] Trailers used.

The cost of gasoline, oil, tires, and labor ranged from 49.2 to 76.8 per cent of the total, the variation being due to type of roads, contour of roads, condition of motor, and the ability of the driver to handle the equipment. Depreciation varied according to the administrative policy of the company. The cost of repairs depended upon the newness and suitability of the equipment and the carefulness of the driver. Labor costs for operation varied with the section of the country.

Table 6 shows the cost of city hauling with tank trucks where they were used as supplemental equipment to unload tank cars spotted on sidings some distances from the main plant. As this hauling was for short distances within the city, the cost per hundredweight mile was high.

TABLE 6.—*Cost of city hauling with tank truck from tank cars at those plants*

Plant No.	Depreciation		Gasoline, oil, and tires		Repairs		Labor	
	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total
1	$0.00133	22.3	$0.00127	21.2	$0.00114	19.1	$0.00218	37.4
2	.00130	20.1	.00143	22.1	.00108	16.6	.00178	27.5
3	.00130	16.5	.00090	12.1	.00203	30.3	.00130	16.9

Plant No.	Interest		Miscellaneous		Total		Distance hauled
	Per hundredweight mile	Percentage of total	Per hundredweight mile	Percentage of total	Per hundredweight mile	Per 100 pounds	
							Miles
1					$0.00592	$0.0593	10
2	$0.00048	7.5	$0.00040	6.2	.00647	.0323	5
3	.00060	8.4	.00120	15.8	.00733	.0233	3

Motor tanks and labor may be made available to the plant in one of three ways: (1) The milk plant may own and man the entire equipment; (2) the plant may furnish the tank and keep it painted and in repair and the hauler furnish motor equipment and men; or (3) the hauler may furnish and man the entire equipment. When either of the last two arrangements exists, the hauling is done by the day, the mile, the load, or at railroad rates. Nearly every dealer arranges to have the name of his company appear conspicuously on the equipment. Table 7 shows the cost of hauling at 10 plants having one of the last two arrangements.

The average cost per 100 pounds hauled was $0.308 where the tank was furnished by the milk plant and $0.30 where all equipment and labor was furnished by the hauler; and the average costs per hundredweight mile were $0.00257 and $0.00309, respectively.

TABLE 7.—*Cost of hauling milk by tank truck with hired labor and equipment*

Plant No.	Cost per 100 pounds	Cost per hundredweight mile	Distance hauled	Type and contour of roads
			Miles	
1 [1]	$0.35	$0.00343	102	Level; concrete and gravel.
4 [1]	.21	.00244	86	Rolling; concrete.
5 [1]	.26	.00200	132	Do.
10 [1]	.41	.00240	170	Very hilly; concrete and macadam.
2 [2]	.23	.00411	56	Level; concrete.
3 [2]	.21	.00262	80	Rolling; concrete and macadam.
6 [2]	.30	.00214	140	Rolling; concrete.
7 [2]	.25	.00357	70	Hilly; concrete.
8 [2]	.36	.00300	120	Hilly; concrete and macadam.
9 [2]	.45	.00313	144	Very hilly; concrete and macadam.

[1] Tank furnished by milk plant.
[2] Tank furnished by hauler.

CONDITIONS UNDER WHICH TANK-TRUCK HAULING IS UNSATISFACTORY

Tank-truck hauling has proved satisfactory to most users; however, conditions such as the following make it uneconomical: small

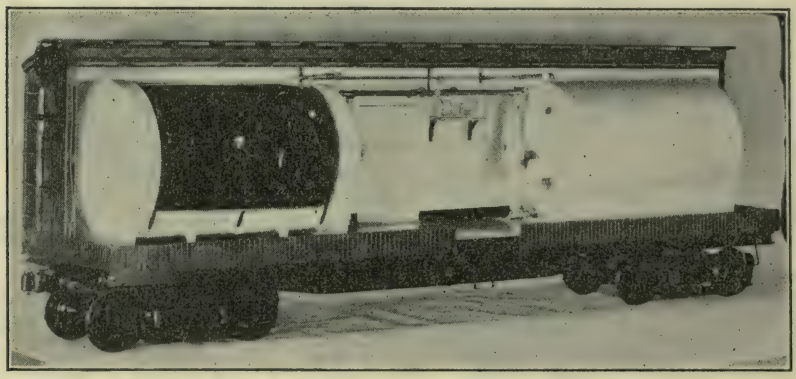

FIGURE 5.—Model showing general arrangement of modern milk tank car

plants, shippers situated a short distance from the plant, small supply of milk from one community, poor roads, and exceedingly long routes where climatic conditions are severe.

TANK CARS

EQUIPMENT

The railroad milk tank car is of the express-car type, and is equipped with 4-wheel trucks designed for high speeds. It is wired for electricity, has a thoroughly insulated body and an acid-resisting waterproof floor sloping to the center of the car and equipped with a drain. The car floor is 4 feet 2⅞ inches above the rails. A glass-lined steel tank is mounted at each end of the car. (Fig. 5.) The standard capacity of a tank is 3,000 gallons, although some recently made tanks hold 3,820 gallons. The tanks are pitched toward the center of the car and insulated with 2-inch cork board protected by a metal covering. They are equipped with a 4-inch inlet; a 20-inch manhole (the doors of some manholes swinging into the tank and others out); a direct motor-driven propeller-type agitator with 2-speed motor; a filter for compressed air; angle stem thermometer; two 5-inch glass

openings in the front head near the top, one with electric light for illuminating the interior; and a 4-inch outlet equipped with a special valve. (Fig. 6.) Some tanks have sampling valves. Accessory equipment in the car may consist of a stationary milk pump or an air compressor; a water reservoir for use in washing the tanks; and a brine system for cooling, although this feature has not come into general use.

It is the usual practice to paint on the car the name of the plant and other advertising matter. Some thought is expended by milk plants on the colors to be used, in order that they be not only pleasing to the eye but also of such a shade that they do not show dust and coal smoke readily. For example, if the cars have to go through

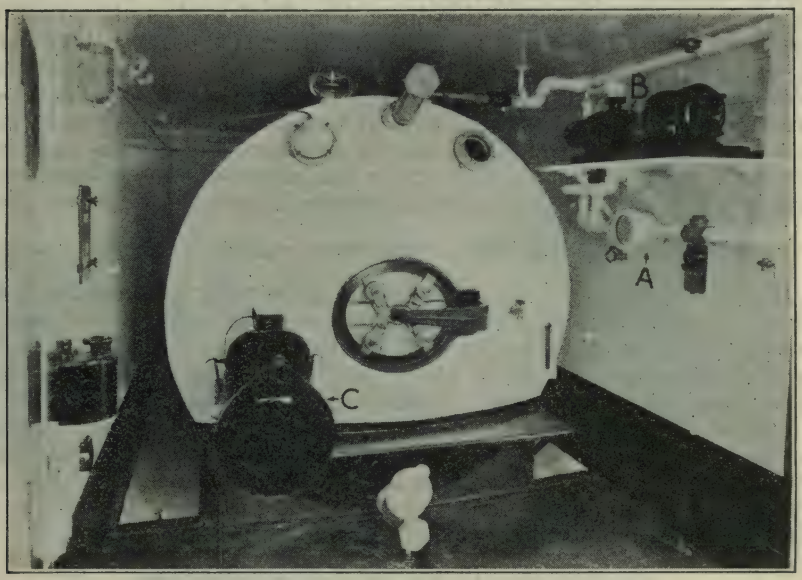

FIGURE 6.—Interior view of one end of a modern milk tank car showing air filter (A), air pump (B), agitator (C), electric wiring, and insulated tank with manhole opening inside

tunnels en route, dark-colored cars are preferable as they do not show the coal smoke as much as light-colored cars.

Milk plants get the use of tank cars in two ways: By purchase from the manufacturers or by daily rental. Repairs on cars are made by the railroad at its shops, and the cost is charged to the company owning or renting the cars. The cost of repairs on eight cars for which data were collected for six years averaged $0.0032 per mile.

LENGTH OF ROUTES AND NUMBER OF CARS REQUIRED

The average 1-way haul by tank cars on 36 routes throughout the country was 122 miles. Eleven per cent of the routes had a 1-way haul of under 50 miles; 22 per cent, between 50 and 100 miles; 42 per cent, between 100 and 150 miles; 14 per cent, between 150 and 200 miles; 5½ per cent, between 200 and 250 miles; and 5½ per cent, between 250 and 300 miles. Tables 8 show the length of 15 routes, time in transit, and the distance covered per hour. This table shows that time en route did not have a direct relation to the distance hauled.

TABLE 8.—*Time of tank cars in transit for routes of different lengths*

Length of haul	Time en route	Distance per hour	Length of haul	Time en route	Distance per hour
Miles	*H. m.*	*Miles*	*Miles*	*H. m.*	*Miles*
50	2 50	17.6	114	4 0	28.5
58	2 0	29.0	116	14 0	8.3
66	2 15	29.3	156	12 0	13.0
76	5 0	15.2	167	14 30	11.5
80	3 20	24.0	180	15 0	12.0
101	4 50	20.9	280	8 0	35.0
108	4 50	22.4	350	48 0	7.3
110	12 0	9.2			

The number of cars required for a route depends upon the railroad schedule, service on connecting lines, length of haul, and method of using the cars. Hauls of 100 to 400 miles usually require three cars. When shipment must be made by fast freight, which is somewhat slower than express or passenger service, an extra car may be required, even for relatively short hauls, in order to maintain the daily schedule. Some plants find it economical and advantageous to use the tank car for storage. Where cars are used for this purpose, enough cars must be provided so that the country stations will have their cars on time.

NEED FOR SUPPLEMENTAL TANKS

If a plant depends to a large extent upon tank cars for its daily supply of milk, it should have some reserve tanks in case of breakdowns, delays in schedule, or bad weather. At what point supplemental equipment should be purchased will depend upon size of the plant, length of routes, and the climatic conditions of the section in which the plant is located. In sections subject to severe snowstorms, extra equipment may be desirable so that the city plant may hold over at the city siding cars of milk for use when shipments are delayed by storms. Tank owners and operators state that a plant with 8 to 10 regular cars should have 1 or 2 cars in reserve.

HANDLING MILK FROM TANK CARS AT CITY PLANTS

In handling milk delivered to the plant by tank cars, three steps are involved: (1) Preparation for unloading, which consists of opening the car, starting the agitator, attaching pipes, taking samples, and opening valves; (2) weighing and unloading the milk; and (3) cleansing the car thoroughly, which includes treating to kill bacteria and closing the car.

Most of the time required in preparing for unloading is used in attaching the pipes. If a sampling valve is present, samples for both bacteria and butterfat are taken from it; where there is no valve, bacterial samples are taken through the manhole of the tank. In the latter case the operator must wait until the milk level is below the bottom of the manhole. If compressed air is used for unloading and there is no sampling valve, samples can be taken from the outlet opening before attaching the pipes. This method is unsatisfactory for obtaining bacterial samples for the following reasons: (1) A small quantity of milk is hard to obtain through the large valve without spilling milk on the floor of the car; (2) this milk flows over considerable area, which may unduly contaminate a small quantity; and (3) the milk collected is that which has stood in the valve.

Weighing the milk from the tank cars is not practiced so much as weighing from tank trucks, because the cars carry the entire receipts of the country plant, whose daily report attached to the tank gives the amount contained, and because the power used for unloading forces the milk directly into the storage tank.

If weighing of the milk is practiced, the 2-hopper scales are generally used; however, the platform scales may be used at plants located away from the siding and where tank trucks are used in transporting the milk from the car to the plant, although they are open to the criticism discussed under tank-truck hauling.

Table 9 shows the results of observations at five city plants where tank cars were spotted on the siding at the plant. This table shows that most of the labor was used in weighing and unloading; in only one plant the number of man-minutes per 1,000 gallons of milk

FIGURE 7.—Spotting a milk tank car by using a motor truck for power

handled was greater for washing and treating than for weighing and unloading.

TABLE 9.—*Methods used and time required in unloading milk from tank cars at five city milk plants having railroad sidings at the plants*

Method of unloading	Preparation		Weighing and unloading		Washing and treating to kill bacteria	
	Per 1,000 gallons	Percentage of total time	Per 1,000 gallons	Percentage of total time	Per 1,000 gallons	Percentage of total time
	Man-minutes		*Man-minutes*		*Man-minutes*	
Air	1.9	6.3	25.1	81.0	3.9	12.7
Do	6.0	13.8	24.8	56.9	[1] 12.8	29.3
Do	4.2	10.8	20.0	51.3	[2] 14.8	37.9
Pump	5.1	14.1	12.6	35.4	18.5	50.5
Do	6.4	22.4	11.6	40.8	10.5	36.8

[1] 7.5 man-minutes used for steaming.

[2] 5 man-minutes used for steaming.

At most city plants situated on a siding, cars are spotted by the railroad engine. In some places the curve of the track may be too great for the engine, and other means must be employed. (Fig. 7.) When cars are unloaded at city plants located on a spur, a long pipe is

usually needed. This is especially true when a large number of cars are spotted at nearly the same time. As this pipe is not mounted with the same care as the piping in the plant, it may have air pockets and therefore should be taken apart every day and washed and treated to kill bacteria.

UNLOADING

Plants located at some distance from the railroad siding use the tank truck to haul milk from the car. Unloading at the car is usually done by compressed air or pump. Gravity may be used, but it was not used at the plants studied. The compressed air either is purchased from the railroad companies, or the milk plant furnishes a portable compressor with electric motor (fig. 8) and pays for its power either through the railroad or direct to the electric-power company. All compressed air should be thoroughly filtered and the filtering material changed often enough to maintain its efficiency. Where

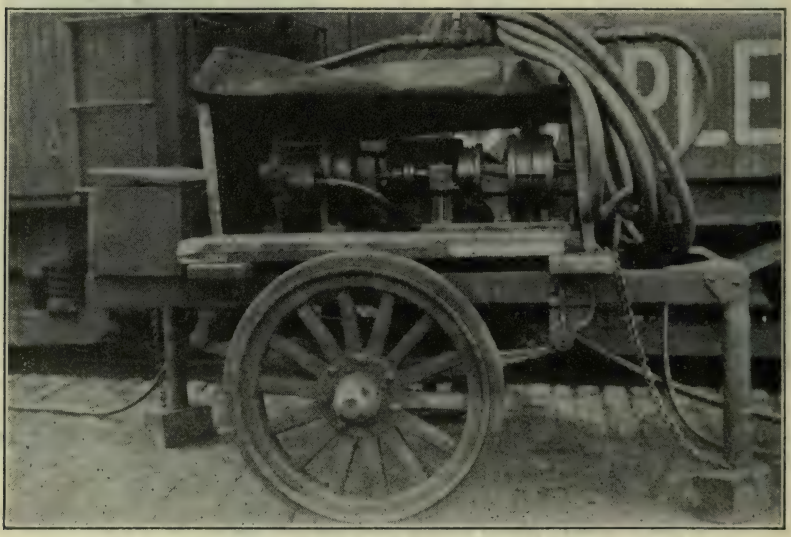

FIGURE 8.—Portable air compressor, fitted with a silencer, for unloading tank cars

pumps are used for emptying the tanks, some heating arrangement should be supplied in cold weather to prevent the milk from freezing in the pump.

How many tank trucks and trailers should a plant have for unloading tank cars where the siding is not located at the plant? The opinion of the operators and owners interviewed was that enough tank trucks should be supplied to unload a car within two or three hours from the time the seal is broken, or a truck and trailer equipment should be able to make at least one trip an hour.

WASHING AND TREATING TO KILL BACTERIA

For tank cars unloaded at the plant, the method of washing and treating to kill bacteria is about the same as the method of washing and treating truck tanks. However, more care must be used in taking apart the valves and piping which are in contact with the milk. The line used for compressed air should be washed and treated to kill

bacteria, as moisture may accumulate at some point and if it is not removed it may add bacteria to the milk.

Table 10 gives complete data on washing tank cars and treating them to kill bacteria at five plants. The average number of man-minutes per tank ranged from 8 to 32. There were considerable differences in the man-minutes required in the same plant, one plant having a range of 22 to 49 man-minutes per tank. The capacity of the tank had no bearing upon the labor used in washing, as is shown by the column "Average time per 1,000 gallons tank capacity, man-minutes." Various kinds and amounts of cleansing powders or soap mixtures were used. These were brushed over the inside of the tanks and thoroughly rinsed off by the force of the water. Some of the powders made the tanks so slippery as to endanger the workmen. Steaming the tanks required much more time than spraying them with a chlorine solution.

TABLE 10.—*Time and materials employed in washing tank cars and treating them to kill bacteria for five plants*

Plant No.	Average time per tank		Range in time per tank	Average time		Average percentage of the total man-minutes used for washing and treating	Average temperature of wash water	Range of temperature of wash water	Washing powder per tank	Method of treating to kill bacteria
	Man-minutes	Minutes		Per 1,000 gallons of milk	Per 1,000 gallons of tank capacity					
			Man-minutes	*Man-minutes*	*Man-minutes*	*Per cent*	*°F.*	*°F.*	*Pounds*	
1	8.0	8.0	7–9	3.9	3.5	12.7	127	126–129	0	None.
2	15.2	29.2	12–18	[1] 15.3	8.1	32.5	179	172–190	0.76	Steam [2]
3	25.2	25.2	22–49	[3] 14.8	11.8	38.1	160	142–171	0	Do.[4]
4	29.9	29.0	22–47	18.5	9.9	50.5	114	90–126	0.93	Chlorine-solution.[5]
5	32.0	32.0	19–45	10.5	10.7	36.8	127	120–135	(6)	Do.[7]

[1] 7.5 man-minutes used for steaming.
[2] To 170° F.
[3] 4.3 man-minutes used for steaming.
[4] To 210° F.
[5] 2.4 quarts.
[6] Soap mixture used.
[7] 2 quarts.

Table 11 shows the temperatures reached by steaming tank cars for the length of time indicated. The time necessary to reach a given temperature depends upon length and size of pipe, insulation, and steam pressure. Probably in but few cases was a satisfactory temperature (200° F. for five minutes) maintained. Owners and operators stated that when tank cars are steamed to high temperatures, 15 to 18 hours, depending upon the outside temperatures, are required for their temperature to become as low as that of the atmosphere. Some plants hasten this lowering of temperature by putting ice in the tank cars and shipping it to the country station, there to be used for cooling the incoming milk.

If chlorine solution is used for treating the inside of the tanks to kill bacteria, it should be applied with a sprayer capable of thorough atomization, as this will insure reaching all parts with a minimum quantity of the chemical.

TABLE 11.—*Temperatures of tank cars reached in steaming for different lengths of time*

Tank car No.	Temperature at start	Temperature reached after steaming for number of minutes stated														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	100	112	113	113	120	126	132	136	141	146	150	155				(1)
2	90	116	120	123	124	128	132	136	140	144	149	153	154	158	164	[2] 168
3	104	106	106	110	113	116	120	126	131	136	140	144	149	154	158	160
4									200							
5										206						
6											210					
7									200							
8										208						
9											210					(3)
10													210			
11														211		
12														212		
13										208						(4)
14												206				
15															208	

[1] 118° at end of 20 minutes.
[2] 120° at end of 40 minutes.
[3] 170° at end of 75 minutes.
[4] 190° at end of 32 minutes.

If the tank car is unloaded at the siding some distance from the city plant, it is the usual practice to rinse the car thoroughly with water from a near-by hydrant or from a supply in special tanks in the tank car. The openings are then left open until the tank reaches the country station, where it is thoroughly washed and treated to kill bacteria. The tank should not be steamed if it is to be used the same day, as it will not cool sufficiently in so short a time.

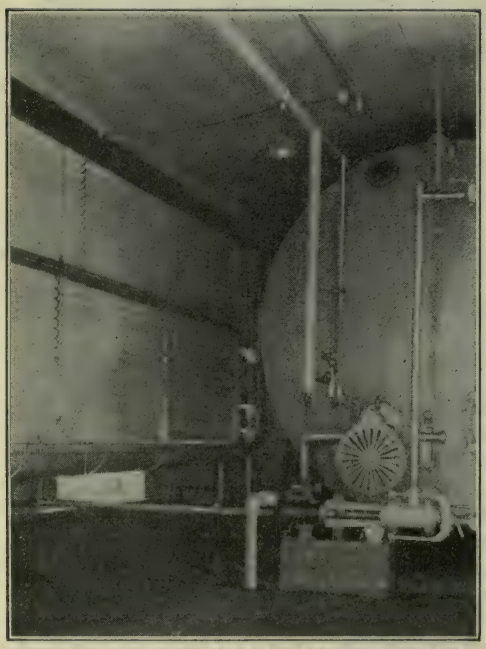

FIGURE 9.—Interior of country milk-receiving station equipped for tank-car hauling

CONDITIONS UNDER WHICH TANK CAR HAULING IS UNSATISFACTORY

Tank-car hauling was considered by the plant owners and operators to be practical and economical, except in certain instances: City plants handling small quantities of milk; plants whose source of supply is within a radius of 30 to 50 miles; small country stations which have less than car-lot shipments for the greater part of the year, unless the railroad allows pick-up privileges and two neighboring stations can furnish a minimum carload at all times; and country stations receiving two grades of milk, neither in sufficient quantity to fill a tank. Some milk-plant operators consider that the protection afforded high-grade or special milks will overbalance the extra cost of shipping small quantities in tanks, although milk in a partly filled tank does not stay at such low temperatures as does milk in a full tank. Where pick-up service is permitted, country stations must be equipped with large storage tanks and facilities for loading quickly. (Fig. 9.)

ADVANTAGES OF HAULING MILK IN TANKS AS COMPARED WITH HAULING MILK IN CANS

The advantages of tank-truck and tank-car hauling over the hauling of milk in cans are as follows: Better temperature control of product, greater sanitation, smaller investment in cans, less loss of milk, less labor at country plants, the handling of more milk in the same area by the city plant, saving in washing powder and in man-hours required for washing, the affording of an advertising medium for firm name and slogans, and reduction in floor space required in country plants.

Insulated tanks protect the milk from both heat and cold, the main problem being to get the milk into the tanks at a low temperature.

Tanks rarely rust with scale formations, which harbor bacteria, and the amount of contact surface per gallon of milk hauled in tanks is much smaller than in cans. For example, a 10-gallon can has a surface of approximately 1,108 square inches, or 110.8 square inches per gallon capacity, whereas a 1,200 or 1,250 gallon tank has a surface of only about 28.9 square inches per gallon capacity.

Owners and operators of trucks who are interviewed were unanimous in saying that tanks save can investment. One man said that each truck saved $1,200 a year in cans; another said that by changing from cans to tanks 7,200 fewer cans were purchased per year; and the records of another showed a saving of $15,000 per year. This refers only to can investment and does not furnish a comparison of this item with the tank itself. In either method of hauling the truck would be necessary.

In whatever way milk is handled there is likely to be some loss. Milk may be lost from tanks through leaky valves, leaky pipe lines, or poor connections. When cars are used the siding may not be level and some milk may be left in the tank. However, these losses are very small as compared with the losses resulting from the use of cans. They are due to milk spilling while the cans are being handled, especially while they are being filled; to milk adhering to the cans after they are dumped; to hurried and incomplete dumping; to leaky cans; and to milk souring because of improper temperature control while the cans are en route, at the terminal station, or at the plant, and because of delays caused by breakdowns.

Less labor is required at country milk-receiving plants, because the milk is transferred from point to point by mechanical means with little supervision, whereas labor must be used in filling, capping, and transferring cans and in unloading, washing, and stacking the empty cans for city shipment.

A comparison was made of the labor required for handling milk in cans at 13 plants, and in tanks, either car or truck, at 21 plants. Comparable operations were taken into consideration. The average number of gallons in cans handled per man-minute was 4.6, and in tanks, 23.5. Delivery in cans varied from 3.0 to 7.1 gallons per man-minute, and in tanks from 12.8 to 35.3 gallons. Nine of the plants used both systems, a comparison of which is shown in Table 12.

The amount of floor space required at the plant to receive the milk in cans depends upon the amount of milk received. Sometimes a point is reached where no more space can be spared for this purpose, yet the plant could put out more milk if the receiving department could handle more in the time allotted. If the plant is already operating under a country-station system, a change to tank hauling

will help to remedy this difficulty. The truck owners and operators stated that they could handle from 40 to 70 per cent more milk in a given space than when the milk was delivered in cans.

TABLE 12.—*Comparison of efficiency of milk delivery by cans and by tanks*

Plant No.	Delivery by cans		Delivery by tanks	
	Per man-minute	Men employed	Per man-minute	Men employed
	Gallons	*Number*	*Gallons*	*Number*
1	3.7	6	27.38	2
2	4.8	6	25.55	2
3	7.1	6	18.69	3
4	5.6	6	19.10	2
5	3.3	9	12.80	3
6	3.7	7	22.50	2
7	4.6	8	33.60	2
8	3.0	5	22.50	1
9	4.5	5	25.60	2

Under certain conditions tank-truck transportation has advantages over tank-car transportation. Where roads are good the country stations can be located at points convenient to their milk supply and independent of railroad sidings. This will usually allow cheaper land to be used for a building site. Another advantage is the saving in cartage from the railroad terminal to the milk plant. Tank-truck transportation is the most flexible type, as the product can be diverted between substations with little labor and at short notice. If a driver on one of the farmer routes is late in reaching the country station, the truck can wait a short time before leaving in order to avoid storing small quantities of milk until the next day, as is often the case when milk is shipped by rail in cans or by tank car.

Tank-car transportation has a number of advantages over delivery by tank trucks which benefit the railroad as well as the plant. As the cars are either rented from the manufacturers or owned outright by the milk plants, the railroad needs to make no investment in them. They eliminate the necessity of platforms at the terminals and do away with the terminal service of unloading the shipments of milk and loading the return empties. The railroad has no expense for ice and no claims for spilled milk. The latter alone amounts to large sums of money when cans are used.

Tank cars reach the city more regularly than the trucks, as trains must be run on schedule. Less storage space at country stations is required, and consequently the cost of refrigeration is less. At some places early schedules of milk trains necessitate the employment of extra help in order to load the cans on time. With tank cars this is not needed, as loading is done by mechanical means. In places where no express milk trains are scheduled, fast freight can be used without undue rises in milk temperature. By providing extra cars, storage tanks at country stations can be saved and extra storage tanks in the city plant eliminated. At present the tank car is the only practical means of extending the milk shed beyond the 330 to 500 mile zone and, at the same time, maintaining the quality of the milk without extra expense en route.

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TECHNICAL BULLETIN No. 244 MAY, 1931

HARVESTING SMALL GRAIN, SOYBEANS, *and* CLOVER *in the* CORN BELT *with* COMBINES *and* BINDERS

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.
IN COOPERATION WITH THE AGRICULTURAL EXPERIMENT STATIONS OF ILLINOIS AND INDIANA

For sale by the Superintendent of Documents, Washington, D. C. - - - Price 15 cents

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The investigation upon which this bulletin is based was conducted cooperatively by the Division of Farm Management and Costs of the Bureau of Agricultural Economics, the Division of Agricultural Engineering of the Bureau of Public Roads, the Division of Cereal Crops and Diseases of the Bureau of Plant Industry, and the agricultural experiment stations of Illinois and Indiana.

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By L. A. REYNOLDSON, *Associate Agricultural Economist, Division of Farm Management and Costs, Bureau of Agricultural Economics;* W. R. HUMPHRIES, *Chief Engineering Aid, Division of Agricultural Engineering, Bureau of Public Roads;* and J. H. MARTIN, *Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry*

IN COOPERATION WITH THE AGRICULTURAL EXPERIMENT STATIONS OF ILLINOIS AND INDIANA

CONTENTS

	Page
Introduction	1
Purpose and extent of study	2
Description of area and type of farming	2
Harvesting equipment	4
Power and labor	7
Methods of harvesting the crops	8
Comparison of harvesting and threshing methods	12
Crops and acres harvested	12
Days on which harvesting was done	14
Rate of harvesting	14
Condition of crop at harvest time	20
Reliability of combines and binders	21
Harvesting and threshing losses	21
Straw saving	24
Costs of harvesting and threshing	24
Labor	25
Power	29
Cost of harvesting and threshing—Continued	
Fuel and lubricants	30
Threshing	32
Repairs	32
Shelter	33
First cost and depreciation	34
Costs for different acreages harvested	35
Acreages on which combines and binders will be economical	39
The harvest season	40
Rainfall	41
Weather conditions	44
Quality and condition of grain	44
Grain handling and storing	47
Cooperative ownership	49
Custom work	50
Summary	52

INTRODUCTION

Within the span of a single lifetime the methods and practices of harvesting small-grain crops have made striking changes from the cradle to the "combine" or combined harvester-thresher. Within that comparatively narrow limit of time, the efficiency of the agricultural worker through the adoption of labor-saving machines and methods has increased his producing power of 1 bushel of wheat in 3.2 hours in the old days of cradle, flail, and horse to 1 bushel in 0.2 hour in the present day of the combine and tractor. The use of the combine has enabled farmers of to-day to effect as great a saving in time, labor, and cost over binder methods as did their predecessors who discarded the cradle for the self-rake reaper.

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The first combined harvester-thresher introduced into the central Corn Belt was used in Illinois in 1924. Since that year the number in the area has increased rapidly. In 1927 approximately 500 machines were being operated, and in 1928 the number had increased. The machines are not centralized in a few districts; they are widely scattered, singly or in small groups, throughout the several States. But it remains a problem with many farmers in these States whether to buy a combine or to continue harvesting with their present equipment.

PURPOSE AND EXTENT OF STUDY

It is the purpose of this bulletin to present the necessary data and to make comparisons between different harvesting methods in order to assist farmers who are considering the purchase of a combine for harvesting their various crops. The information on which the comparisons are based was obtained from farmers in Illinois who operated combines and from farmers in Indiana who operated combines or binders, by the United States Department of Agriculture, cooperating with the agricultural colleges and experiment stations of Illinois and Indiana. Information was recorded from all the combine and binder operators with whom it was possible to make contact. In Illinois the farmers kept daily records of the details of their harvesting operations on blanks furnished them. These records were frequently examined by an investigator who called on each cooperator several times during the harvest season. The combine owners were well scattered throughout the small-grain sections of the two States; the binder operators were more centralized. Published information regarding binders and threshing machines is here used to supplement that which was obtained by this study.

This bulletin should be of assistance to farm-equipment dealers who are selling combines for the first time, to college-extension workers who are called upon for information by various farm agencies, to county agents or advisors who are consulted by their farmers, and to farmers themselves who already own combines or contemplate the purchase of one.

DESCRIPTION OF AREA AND TYPE OF FARMING

The area in which the combine study was made includes the bulk of the small-grain sections of Illinois and Indiana, in which natural conditions are practically similar. The soils are fairly uniform, with black loams predominating. Some clay and sandy loam also occur in different sections, the latter sometimes giving rather uncertain footage for the tractor and causing a lowered daily acreage. The topography in the area included is level with the exception of a few fields that might be termed "rolling". The rainfall and humidity throughout the area are similar. Dews, which occur somewhat frequently, cause a delay in starting in the morning as compared with areas in the Great Plains where the atmosphere is less humid. Conditions under which the study of binders was made were similar.

A system of general farming prevails throughout the area, in which corn, small grain, legumes, and livestock are the most important products. Corn occupies the largest acreage of any single crop on the farms where records were obtained, but is not considered in the discussion of harvesting. Wheat occupies the largest acreage of any of

the crops harvested on the farms that have combines, but is second to oats on the farms using binders. Soybeans are another inportant crop, especially on the farms of the men who own combines, where they occupy an average of 38 acres. Practically the same acreages of legumes other than soybeans are found on the farms that use combines and those that use binders. On the farms using combines the average acreages of soybeans and of other legumes were practically the same. Of the average 355 acres in crops, the combines could have been used to harvest 214 acres, or 60 per cent. Of these 214 acres, wheat occupied 79, oats 52, soybeans 38, other legumes 33, and barley 12 acres.

The average number of acres in crops on farms of different sizes on which combines and binders were used is shown in Table 1.

TABLE 1.—*Average number of acres in crops and other land on farms of different sizes on which combines and binders were used*

Farm area	Farms	Size of farm	Crops						
			Grain				Soybeans	Other legumes	
			Wheat	Corn	Oats	Barley		Sweet clover	Red clover
Combine farms:	*Number*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
200 acres or less	18	167	31	47	15	4	23	7	3
201 to 300 acres	20	249	41	76	38	5	26	5	5
301 to 400 acres	29	352	56	99	48	16	37	11	7
401 to 500 acres	10	466	91	143	58	12	45	-------	25
501 to 600 acres	12	558	128	161	59	23	30	11	22
601 acres and over	18	904	166	262	100	16	68	43	20
Total or average	107	429	79	124	52	12	38	14	11
Binder farms:									
200 acres or less	14	160	29	42	32	1	2	5	11
201 to 300 acres	17	260	35	72	38	-------	17	6	20
301 acres and over	12	398	55	122	60	1	11	-------	33
Total or average	43	266	39	76	42	1	10	4	21

Farm area	Crops								
	Other legumes—Continued				Miscellaneous	Total cultivated	Rotation pasture	Permanent pasture	Other land
	Alsike clover	Mixed clover	Alfalfa	Total other legumes					
Combine farms:	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
200 acres or less	1	-------	2	13	4	137	3	19	8
201 to 300 acres	2	2	2	16	9	211	2	25	11
301 to 400 acres	5	2	3	28	6	290	8	44	10
401 to 500 acres	8	5	2	40	9	398	2	52	14
501 to 600 acres	-------	-------	4	37	21	459	9	66	24
601 acres and over	-------	4	5	72	56	740	45	83	36
Total or average	3	2	3	33	17	355	12	46	16
Binder farms:									
200 acres or less	3	2	1	22	3	131	7	13	9
201 to 300 acres	3	-------	1	30	3	195	15	34	16
301 acres and over	2	7	3	45	11	305	16	52	25
Total or average	3	3	1	32	5	205	13	32	16

The organization on the farms that use binders, with the exception of the acreage in soybeans, is practically the same as in the three smaller groups of combine farms. The combine has proved more efficient than any other machine for harvesting this crop in this area, which probably accounts for the difference in the acreage of this one crop. It is probable that were the binder operators to buy combines, the acreage of soybeans would increase on their farms, or if larger acreages of soybeans were grown, combines would be bought to harvest them.

On the farms studied, livestock as an enterprise is relatively as important as the growing of crops. Of all classes of animals, hogs were more numerous than any other. Table 2 shows the average number of each class of livestock on combine and binder farms in Illinois and Indiana.[1]

TABLE 2.—*Average number of livestock on combine and binder farms in Illinois and Indiana*

Group	Number of farms[1]	Average number per farm										
		Horses		Cattle				Swine			Sheep	Poultry
		Work	Other	Milk cows	Beef cattle	Young cattle	Total	Sows	Other hogs	Total		
Combine farms:												
Illinois	67	10	2	9	8	5	22	14	92	106	10	146
Indiana	38	8	1	6	10	5	21	12	155	167	25	199
Binder farms: Indiana	42	6	1	7	12	6	25	11	57	68	38	162

[1] The number of farms, or combines, and binders included in this and subsequent tables are not always equal to total number of records obtained because of incomplete data for some items.

Although the number of work horses on the binder farms is smaller than on the combine farms, the average is about the same for both classes of farms of the same size. The number of work horses on these farms was affected little, if any, by the purchase of a combine, which in all instances was pulled by a tractor, as in the majority of the instances the farmer owned his tractor before he bought his combine. Reductions in the number of work stock through the use of a tractor were made previous to the purchase of combines, which accounts for approximately the same number of like-sized farms of the two classes.

HARVESTING EQUIPMENT

All the combines owned on the farms were purchased in 1926 or 1927, whereas some of the binders were purchased as far back as 1897. Table 3 shows the number of combines and binders by size and by year of purchase.

[1] The number of farms, or combines, and binders included in Table 2 and subsequent tables are not always equal to the total number of records obtained because of incomplete data for some items.

TABLE 3.—*Size and year of purchase of the combines and binders*

Year of purchase	Combines					Binders				
	8-foot	9-foot	10-foot	12-foot	Total	6-foot	7-foot	8-foot	10-foot	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1897						1				1
1898							1			1
1900							1			1
1902								1		1
1908								1		1
1912						1		1		2
1913								3		3
1915							3	2		5
1916								2		2
1917								2		2
1918								1		1
1919								2		2
1920								4		4
1921								1		1
1922							1	1		2
1924								2	2	4
1925							1	3	1	5
1926	1		11	8	20			1	1	2
1927	7	9	61	10	87				1	1
Total	8	9	72	18	107	2	[1] 7	[1] 27	5	41

[1] Does not include one old machine, purchase date of which was not reported.

FIGURE 1.—The small type of combine used in the Corn Belt. These machines are less expensive than larger outfits and do the work satisfactorily

As compared with combines in the Great Plains, the machines in this area are smaller sized. (Fig. 1.) As the fields and acreages to be harvested are smaller, the smaller and less expensive outfits will do the work satisfactorily, and they can pass through the necessary gates and lanes, and over bridges. Less than one-fifth of the combines were purchased in 1926. The success of these machines in the hands of their operators and the heavy damage from rains to shocked grain in 1926 was no doubt responsible for the more than fourfold increase in 1927.

Many of the binders have seen extended service, the oldest having been in operation for 30 seasons. Five of the binders bought within the last few years are power-driven outfits. These are 10-foot

machines and obtain their operating power from the tractor used to pull them. Practically all the other binders in use cut an 8-foot swath. This size outnumbered the two smaller sizes three to one.

Combines purchased in all sections prior to 1926 and many of those purchased in 1926 and 1927 did not include, in the first cost, some of the equipment that many operators wanted for use on their machines. The tendency of manufacturers at present, however, is to place on the market machines already equipped with some of the more necessary items which were formerly considered as extra. Many of the operators had their machines fitted with items of extra equipment at the time of purchase; others bought the items later as the need became apparent. The common items of such equipment, bought by owners in the Corn Belt, are the grain tank, the straw spreader, the speed-reducing sprockets, and the soybean attachment.

All combines are built in one of two types—tractor-drawn with power take-off or with an auxiliary motor. Machines of the first type have cutter bars 8 to 10 feet long. Some makes can be equipped with an auxiliary motor when the power delivered by the tractor is not sufficient in heavy stands of grain or on light sandy soil. A few men who owned such machines had put auxiliary motors on them. A machine of the second type cuts a swath from 9 to 24 feet wide and is drawn by a tractor or by horses.

Table 4 shows the number of combines of each type and size and the accessory equipment used.

TABLE 4.—*Numbers of combines of each type and size having various items of accessory equipment*

Type of combine	Width of cut	Number of combines	Straw spreader	Straw buncher	Wagon hitch	Grain tank	Soybean attachment	Clover attachment	Speed reducing sprocket
	Feet								
Tractor drawn, with power take off	8	8	7			8	1	2	2
	10	41	41	1	1	40	19	2	16
Tractor drawn, with auxiliary engine	9	9	9	1		9	3		2
	10	31	31	4	9	26	11		15
	12	18	17	1	8	11	3	1	10
Total		107	105	7	[1]18	[1]94	37	5	45

[1] Five operators had both a wagon hitch and a grain tank.

The straw buncher, with which seven of the machines were equipped, is used for holding a certain quantity of straw as it comes from the machine and then dropping it in a pile. Straw handled in this way is easily hauled, burned, or baled.

Not all the machines used for harvesting soybeans or clover were equipped with attachments for handling these crops. Only about a third of the operators had bought a soybean attachment. The speed-reducing sprockets were used on nearly one-half of the machines. This attachment is used to reduce the speed of the cylinder in harvesting soybeans, and to a large extent it prevents the beans from cracking.

Five operators had both a wagon hitch and a grain tank. They bought the cheaper wagon hitch when they bought the machine but later found a grain tank more convenient.

Many machine operators buy a transport wheel or truck for use when the combine is moved along roads and through lanes, as is common in the Corn Belt.

Among the more recent accessories are the windrow and pick-up units; the crop is cut and laid in a windrow and is later picked up by the combine and threshed. The chief advantages are the elimination of the green-weed problem, for weeds dry out in the windrow, and the fact that the crop may be cut several days earlier than in straight combining. These items were introduced in 1927, but neither one was used on the farms studied.

POWER AND LABOR

All the 107 combines included in this study were drawn by tractors. Approximately 46 per cent of this number were power take-off outfits and the remaining 54 per cent were provided with auxiliary motors. Of the power take-off outfits, 8 were 8-foot and 41 were 10-foot machines. The smaller outfits were operated by tractors with drawbar ratings of about 10 horsepower; the larger outfits used tractors of about 15 horsepower. For each size of combine the size of the tractor was uniform, as this type of combine is made with the intention of operating it in conjunction with tractors of a particular size and make.

The tractors used for pulling the auxiliary-motored combines, show a range of three sizes in use for some of the machines with the same width of cut. This is accounted for by the fact that practically all the tractors had already been purchased for other work on the farm. Under such circumstances the tractor may not be the one best suited to the size of combine, but it is more economical to use it than to purchase or trade for a new one. Soil types and topography may sometimes account for differences in size of tractors used on the same size of combines. On some farms on which the soil is of a light sandy texture the power requirements are greater than on those having the black loam common to the Corn Belt. The farms with rolling fields require tractors of larger size than do the more common level farms. Every combine owner soon learns that the tractor must be of sufficient size to furnish a steady flow of power under all conditions. This is even more important with the power take-off outfits as a reduction in the speed of the cylinder reduces the threshing efficiency. In a number of instances the power take-off outfits had been equipped with an auxiliary engine because the tractor did not have sufficient power for conditions that existed on the farm where the machine was owned.

Of the 43 binder operators interviewed, 70 per cent used horses and 30 per cent used tractors to pull their machines. The 30 horse-drawn outfits had cutter bars of 6, 7, or 8 feet, with the larger size outnumbering the smaller sizes 4 to 1. Operators of the 6-foot binders used 3-horse teams, and those having 7 and 8 foot machines used 4-horse teams exclusively. The 13 tractor-drawn binders were about equally distributed among the 7, 8, and 10 foot sizes. Eight men used tractors to pull machines formerly drawn by horses. The remaining five had purchased power take-off binders. The tractors used to pull these machines also furnish power to operate the cutting and binding mechanism. Three-fourths of the tractors used to pull the binders had a drawbar rating of 9 to 12 horsepower. Compared with the small combine a binder is a light load for a tractor, so the power is sufficient under almost any soil type, crop, or topographical condition.

The power and labor used on combines and binders of different types and sizes are shown in Table 5.

TABLE 5.—*Power and labor used on combines and binders of different types and sizes*

Type of combine	Width of cut (feet)	Number of combines	Number of combines using—					
			Tractor with drawbar rating of—			Man labor		
			12 horsepower or less	15 or 16 horsepower	17 or 18 horsepower	Combine operators	Helpers	Tractor drivers
Tractor, drawn with power take-off	8	8	8			1		8
	10	41		41		33	1	41
Tractor drawn, with auxiliary engines	9	9	6	3		9		9
	10	31	11	19	1	29	2	31
	12	18	6	9	3	18	2	18
All types		107	31	72	4	90	5	107

Type of binder	Width of cut (feet)	Number of binders	Number of binders using—						
			Tractor with drawbar rating of—		Horses		Man labor		
			9 to 12 horsepower	15 horsepower	3 horses	4 horses	Binder operators	Shockers	Tractor drivers
Tractor drawn	7	4	4				2	9	4
	8	4	3	1			2	8	4
	10	5	2	3			1	21	5
Horse drawn	6	2			2		2	3	
	7	4				4	4	8	
	8	24				24	24	50	
All types		43	9	4	2	28	35	99	13

Of the combines having auxiliary motors 60 per cent were drawn by tractors with a drawbar rating of 15 to 18 horsepower. According to information obtained in the Great Plains, tractors of 15 drawbar horsepower have sufficient power to pull the 15 and 16 foot combines which are the size most commonly found there, and larger tractors are seldom necessary. As contrasted with operation in the Great Plains [2] none of the Corn Belt operators interviewed used horses as the motive power for their outfits.

The number of men required for combining and for binding and shocking are included in Table 5. The power take-off outfits are intended primarily for operation by one man. All but one of the 8-foot combines were so operated, but the majority of owners of the 10-foot size used a 2-man crew each. The number of shockers with each size and type of binders averaged about two per machine with the exception of the 10-foot outfits.

METHODS OF HARVESTING THE CROPS

The average acreages of different crops that could be harvested with a combine or binder are shown in Table 1, together with the acreage of all crops. Table 6 shows the number of combines and binders used for harvesting different acreages of crops.

[2] REYNOLDSON, L. A., KIFER, R. S., MARTIN, J. H., and HUMPHRIES, W. R. THE COMBINED HARVESTER-THRESHER IN THE GREAT PLAINS. U. S. Dept. Agr. Tech. Bul. 70, p. 14. 1928.

TABLE 6.—*Distribution of combines and binders by average acres of specified crops cut annually and by size*

Area cut annually with combine	Wheat				Oats				Barley				Soybeans				Clover				Miscellaneous crops			
	Combines				Combines				Combines				Combines				Combines				Combines			
	8-foot	9-foot	10-foot	12-foot	8-foot	9-foot	10-foot	12-foot	8-foot	9-foot	10-foot	12-foot	8-foot	9-foot	10-foot	12-foot	8-foot	9-foot	10-foot	12-foot	8-foot	9-foot	10-foot	12-foot
Acres:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
25 and less		2	4		1	2	9	3		2	8	1	1	1	8				14	3	1	1	5	1
26 to 50	2		7	4	4		12	4		1	5	1	2	1	12			1	3			1	2	
51 to 75	2	1	12	1	1	3	12	1	1	1	1	3			4	4			2	1			2	
76 to 100	2	2	9	2		1	9	3			2	3	2		2	1			2				1	1
101 to 125	2	2	12			2	3	2			1	1		2	6	1			1					
126 to 150		1	12	4	1		2	1							4								1	
151 to 175			7	2			1	1				1			5	1			1					
176 to 200			1	3			2				1	1			1	1								
201 to 225			2				1	1																
226 to 250															2									
251 to 275															3					1				
276 to 300			1	1											1									
301 to 325			1												1									
326 to 350							1								1									
351 to 375																							1	
376 to 400															1									
Total	8	8	68	17	7	8	52	16	1	4	18	11	5	4	51	8		1	23	5	1	2	12	2

TABLE 6.—*Distribution of combines and binders by average acres of specified crops cut annually and by size*—Continued

Area cut annually with binder	Wheat				Oats				Barley				Soybeans				Clover				Miscellaneous crops			
	Binders				Binders				Binders				Binders				Binders				Binders			
	6-foot	7-foot	8-foot	10-foot	6-foot	7-foot	8-foot	10-foot	6-foot	7-foot	8-foot	10-foot	6-foot	7-foot	8-foot	10-foot	6-foot	7-foot	8-foot	10-foot	6-foot	7-foot	8-foot	10-foot
Acres:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
25 and less	1		5			2	5	1			1	1		1				1	2			1	4	
26 to 50		5	10	1	1	3	11	1													1			
51 to 75		2	7	1		1	7																	
76 to 100			2	1			2	2							1									1
101 to 125				1																				
126 to 150							1																	
151 to 175																								
176 to 200																								
201 to 225																								
226 to 250								1																
Total	1	7	24	4	1	6	26	5			1	1		1	1			1	2		1	1	4	1

Of the 107 combine operators, 101 used their machines to harvest wheat. Only 4 of this number used a binder to harvest any part of the wheat crop, and 2 used them merely to open up the fields. One operator who harvested 300 acres cut one-half of the acreage with each machine. The binder, he stated, was used so that he would have sufficient straw to meet his requirements. The 6 remaining combine owners had no wheat to cut.

Of 43 farms on which binders were used, 36 operators harvested an average of 45 acres of wheat, and the other 7 did not have wheat to harvest.

Eighty-three men used combines to harvest oats. None of these men used a binder on any part of this crop. Of the other 24 combine operators, 16 used binders to harvest their oats and 8 had none to harvest. A number of men using binders cut their oats for bundle

FIGURE 2.—In the Corn Belt the farmer who uses a combine uses it instead of the binder and mower for harvesting soybeans, as it saves a larger percentage of the crop

feed, and in a number of instances the crop was going down badly on account of rust.

Of 38 binder operators who grew oats, each harvested an average of 50 acres of this crop.

Sixty-eight of the 107 combine owners harvested soybeans with their outfits. During the short time combines have been used in the Corn Belt, experience has shown that they save a much higher percentage of the beans than are saved when any other method of harvesting and threshing is used. (Fig. 2.) Of the remaining 39 men, 22 did not have soybeans to harvest, 5 used a mower and put up soybean hay, and 12 did not state how the crop was handled. It is probable that these 12 men hogged-off their beans or cut them for hay or used a binder. As the records on all but 2 binder farms were obtained before soybean harvest the remainder do not include information as to how the crop was harvested.

Only 36 of the combine owners grew barley. Of this number 34 used the machines to harvest the crop, and the other 2 used binders. On the binder farms only 2 men harvested barley, probably because of the dislike of handling this crop largely by hand.

Twenty-nine of the operators who had clover of different varieties harvested the crop with their combines. The others used the crop for hay or pasture or cut it for seed by some other method. Three binder operators used their machines for harvesting clover. Often considerable difficulty is experienced in harvesting sweet-clover as compared with other clovers. However, records for all clovers were combined because of the comparatively small number of operators harvesting each different clover.

For harvesting miscellaneous crops, such as buckwheat, rye, and millet, 17 men used their combines. Of men using binders, only 7 had any of the miscellaneous crops to harvest.

The large number of crops harvested with combines and the relatively large number of Corn Belt farmers using combines on each crop are no doubt surprising to farmers in the area who are not familiar with combine operations. Most of the farmers interviewed bought their combines for the purpose of harvesting their large acreages of soybeans and wheat without considering the possibilities of using the combines on other crops. After a little experience in harvesting these crops it was natural that they should try combining other crops. In most instances, results were successful. Probably each harvest season hereafter will see more widespread use of combines for harvesting crops that are now cut with binders.

COMPARISON OF HARVESTING AND THRESHING METHODS

CROPS AND ACRES HARVESTED

Of the combine owners who used their machines to harvest different crops on their own farms, 101 harvested an average of 74 acres of wheat, 83 harvested an average of 48 acres of oats, 34 harvested an average of 34 acres of barley, 68 harvested an average of 48 acres of soybeans, 29 harvested an average of 16 acres of clover, and in addition a small acreage of rye, buckwheat, millet, and timothy was also harvested by a few operators.

Of the binder operators who grew different crops, 36 harvested an average of 45 acres of wheat, 38 harvested an average of 50 acres of oats, and only 7 had any miscellaneous crops which were harvested with binders.

The average acreages of all crops cut by combines and binders of different types and sizes are shown graphically in Figure 3. Both custom cutting and harvesting on the home farm are included. The acreages cut by combines and horse-drawn binders were in proportion to the width of cut except that, as the 8-foot tractor-drawn binders were not used for custom cutting, they harvested a slightly lower acreage than did the 7-foot tractor-drawn binders.

Table 7 shows that on an average the combines harvested 263 acres and the binders 98 acres. The 10-foot binders that were operated by a power take-off from the tractor cut an average of 176 acres. The 7-foot tractor-drawn binders cut more and the 8-foot tractor-drawn binders cut less than the horse-drawn binders of the same sizes, but the number of all types except the 8-foot horse-drawn binders was too small for definite conclusions as to the capacity of the binders.

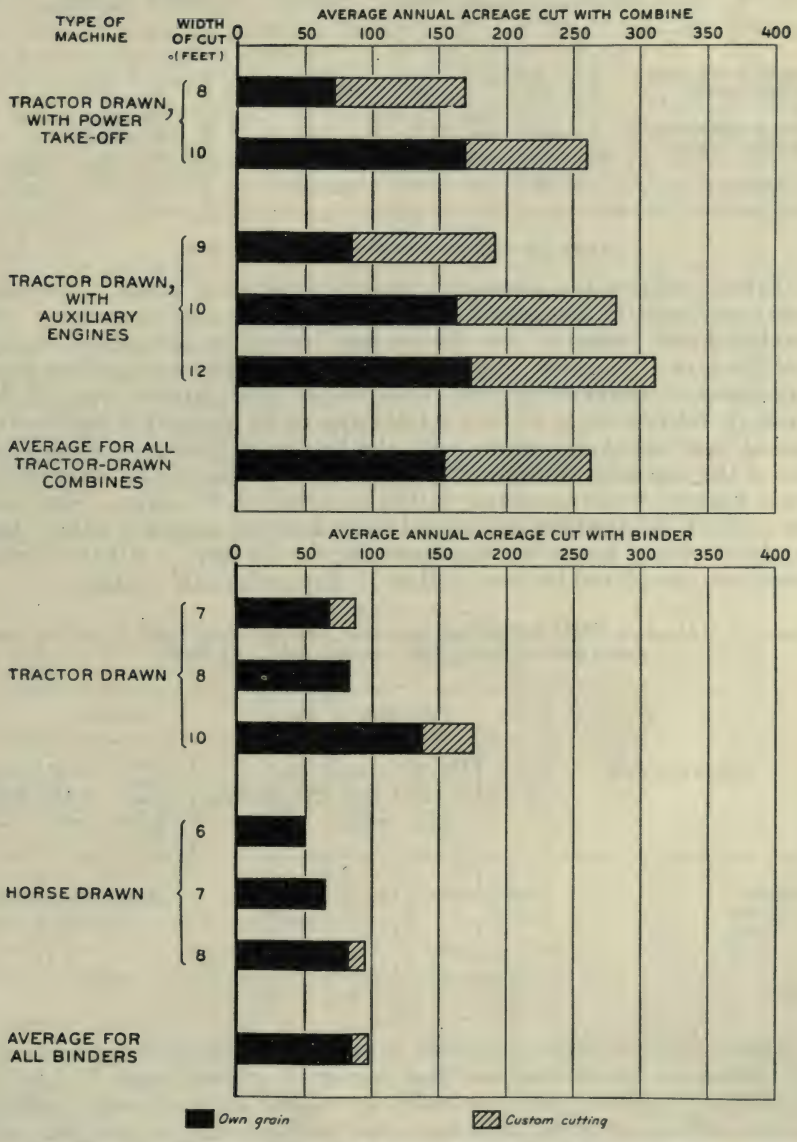

FIGURE 3.—AVERAGE ACREAGE OF ALL CROPS CUT BY COMBINES AND BINDERS OF DIFFERENT TYPES AND SIZES ON THE HOME FARM AND FOR NEIGHBORS

For combines and binders the total acreage harvested by machines used on the home farm and for custom work is in proportion to the width of cut.

TABLE 7.—*Average acreage harvested by 107 combines and 43 binders*

Type of combine	Width of cut	Acres, own crop	Acres, custom cutting	Total acres	Type of binder	Width of cut	Acres, own crop	Acres, custom cutting	Total acres
	Feet					*Feet*			
Tractor drawn, with power take-off	8	72	98	170	Tractor drawn	7	68	19	87
	10	169	91	260		8	83		83
						10	138	38	176
Tractor drawn, with auxiliary engine	9	85	107	192	Horse drawn	6	50		50
	10	163	119	282		7	65		65
	12	174	137	311		8	83	12	95
Average		154	109	263	Average		85	13	98

DAYS ON WHICH HARVESTING WAS DONE

Table 8 shows the average number of days on which harvesting was done and the average number of full days used in cutting with combines and binders. On the average, combines were used 14 days and binders 17 days in small-grain harvest. The average time actually spent in harvesting with combines in both States was 7.6 full days, or 52 per cent, while 5.4 full days, or 32 per cent of the harvest period, was spent in cutting with the binder in Indiana. On all but one of the combine farms and on all but five of the binder farms small-grain harvest was completed within a period of 28 days. Sixty-one per cent of the farmers completed their harvest within 8 days. One combine owner, however, was operating for 23 days. All the binder operators completed harvest within 12 days of actual cutting.

TABLE 8.—*Days on which harvesting was done and full days used in cutting small grain and soybeans with combine and with binder*

Method and State	Small grain				Soybeans			
	Farms	Days on which harvesting was done	Full days used in cutting	Percentage of days used	Farms	Days on which harvesting was done	Full days used in cutting	Percentage of days used
Combine:	*Number*	*Number*	*Number*	*P. ct.*	*Number*	*Number*	*Number*	*P. ct.*
Illinois	36	13	7	54	20	7	4	57
Indiana	30	16	8	50	12	7	5	71
Total or average	66	14	7.6	52	32	7	4.6	66
Binder: Indiana	38	17	5.4	32				

The number of days combines were used for harvesting soybeans on individual farms was less than for small grains, being 7 days, of which the combines were actually operating 4.6 full days. Buckwheat and the clovers were harvested between the small-grain and soybean harvests.

RATE OF HARVESTING

The number of combines and binders harvesting various acreages per day of the different crops is shown in Table 9. Eight-foot combines cut an average of about 13 acres; 9-foot, 15 acres; 10-foot, 20

acres; and 12-foot combines, 24 acres of small grain a day. The 8-foot and 9-foot combines cut an average of less than 10 acres and the 10-foot and 12-foot machines less than 15 acres of soybeans a day. The combines cutting soybeans were operated during fewer hours each day than when cutting small grains. The rate of harvesting clovers was about the same as for harvesting soybeans.

The 6-foot binders cut an average of 14 acres; the 7-foot, 16 acres; the 8-foot, 18 acres; and the 10-foot binders 34 acres of small grain a day. The 10-foot binders were all drawn by tractors and were operated by a power take-off from the tractor and some of the smaller binders were drawn by tractors. The rate of harvesting soybeans and clovers with binders was considerably less than of harvesting small grain.

The average rate of travel when havesting with combines was about 2.7 miles an hour in the case of small grains and soybeans, but was only 1.8 miles an hour when cutting clovers and timothy. The average rate for the tractor-drawn binders was estimated at 3.2 miles an hour. The rate for horse-drawn binders was not determined definitely but can be calculated at about 2.3 miles an hour by comparing the acreage cut per hour by tractor-drawn and horse-drawn binders. The tractor-drawn binders cut an average of 0.31 acre, but the horse-drawn binders cut only 0.23 acre an hour per foot of width.

TABLE 9.—*Distribution of combines and binders, by acres, of specified crops cut per day and by size of machine*

Area cut per day	Wheat combines				Oats combine			
	8-ft.	9-ft.	10-ft.	12-ft.	8-ft.	9-ft.	10-ft.	12-ft.
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
10 acres and less		3	2			1	3	
11 to 15 acres	7	1	10		6	1	9	
16 to 20 acres	1	4	33	5	1	6	19	2
21 to 25 acres			17	5			12	8
26 to 30 acres			6	4			5	6
31 to 35 acres				3			3	
Total	8	8	68	17	7	8	51	16
Average cut by size group	*Acres* 12.9	*Acres* 13.1	*Acres* 19.1	*Acres* 24.7	*Acres* 13	*Acres* 17.6	*Acres* 20	*Acres* 24.6

Area cut per day	Barley combines				Soybeans combines				Clover combines			
	8-ft.	9-ft.	10-ft.	12-ft.	8-ft.	9-ft.	10-ft.	12-ft.	8-ft.	9-ft.	10-ft.	12-ft.
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
10 acres and less		1	1		5	4	14			1	10	2
11 to 15 acres	1	1	3				23	6			10	1
16 to 20 acres		2	8	2			9	2			1	2
21 to 25 acres			2	5			1					
26 to 30 acres			4	4								
31 to 35 acres												
Total	1	4	18	11	5	4	47	8		1	21	5
Average cut by size group	*Acres* 12	*Acres* 14	*Acres* 20.4	*Acres* 23.3	*Acres* 7.3	*Acres* 9.7	*Acres* 12.6	*Acres* 13.9	*Acres*	*Acres* 7.5	*Acres* 11.1	*Acres* 13.9

TABLE 9.—*Distribution of combines and binders, by acres, of specified crops cut per day and by size of machine*—Continued

Area cut per day	Wheat binders				Oats binders			
	6-ft.	7-ft.	8-ft.	10-ft.	6-ft.	7-ft.	8-ft.	10-ft.
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
10 acres and less		1	1			2		
11 to 15 acres	1	2	7		1	1	9	
16 to 20 acres		4	9			3	11	
21 to 25 acres		1	4				5	1
26 to 30 acres			1	1				1
31 to 35 acres			1	2				
36 to 40 acres								3
41 to 45 acres				1				
Total	1	8	23	4	1	6	25	5
Average cut by size group	*Acres* 15	*Acres* 16	*Acres* 18.5	*Acres* 35.9	*Acres* 13	*Acres* 15	*Acres* 17.3	*Acres* 32.9

Area cut per day	Barley binders				Soybean binders				Clover binders			
	6-ft.	7-ft.	8-ft.	10-ft.	6-ft.	7-ft.	8-ft.	10-ft.	6-ft.	7-ft.	8-ft.	10-ft.
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
10 acres and less			1			1				1	2	
11 to 15 acres							1					
16 to 20 acres												
21 to 25 acres												
26 to 30 acres												
31 to 35 acres				1								
36 to 40 acres												
41 to 45 acres												
Total			1	1		1	1			1	2	
Average cut by size group	*Acres*	*Acres*	*Acres* 13.6	*Acres* 33.3	*Acres*	*Acres* 4.8	*Acres* 15.4	*Acres*	*Acres*	*Acres* 8	*Acres* 9.2	*Acres*

The average number of hours per day in actual cutting was less in harvesting clovers and soybeans than in harvesting small grains, because the harvesting came later in the season when the days were shorter and dews more frequent.

The rates of harvesting various crops per day, per hour, and per foot of width by combines and binders of different types and sizes are shown in Table 10 as are the yields per acre, the rate of travel, and length of day. There was no essential difference in the rates of harvesting wheat, oats, and barley. The 10-foot power take-off combines cut at about the same rate as did the machines of the same size with auxiliary engines. The average acreage of small grain cut per hour per foot of width of cut was about 0.21 acre and the corresponding areas for soybeans and clovers were 0.19 and 0.14 acre, respectively.

TABLE 10.—*Acres of specified crops cut per day, per hour, and per foot of width by combines and binders of different types and widths*

WHEAT

Type of machine	Width of cut	Machine	Yield per acre	Rate of travel	Length of day	Cut per day	Cut per hour	Cut per hour foot of width
	Feet	*Number*	*Bushels*	*Miles per hour*	*Hours*	*Acres*	*Acres*	*Acres*
Combine:								
Tractor drawn, with power take-off	8	8	17	2.2	8.6	13	1.5	0.19
	10	39	16	2.6	8.6	19	2.2	.22
Tractor drawn, with auxiliary engine	9	8	19	2.6	7.2	13	1.8	.20
	10	29	18	2.7	9.0	19	2.1	.21
	12	17	18	2.8	9.1	25	2.7	.22
All tractor drawn		101	17	2.7	9.0	19	2.1	
Binder:								
Tractor drawn	7	4	16	3.5	9.5	19	2.0	.29
	8	4	24	3.0	9.3	25	2.7	.34
	10	4	21		10.5	36	3.4	.34
All tractor drawn		12	21	3.2	9.9	26	2.7	
Horse drawn	6	1	28		8.0	15	1.9	.32
	7	4	20		8.9	13	1.5	.21
	8	19	21		9.7	17	1.8	.22
All horse drawn		24	21		9.5	16	1.7	

OATS

Combine:								
Tractor drawn, with power take-off	8	7	28	2.2	8.7	13	1.5	0.19
	10	28	25	2.8	8.8	19	2.2	.22
Tractor drawn, with auxiliary engine	9	8	30	2.8	8.6	18	2.1	.23
	10	23	27	2.8	9.0	21	2.3	.23
	12	16	35	2.8	9.5	25	2.6	.22
All tractor drawn		82	29	2.8	8.9	20	2.2	
Binder:								
Tractor drawn	7	3	11		9.3	18	1.9	.27
	8	2	43		9.0	18	2.0	.25
	10	5	32		10.4	33	3.2	.32
All tractor drawn		10	29		9.8	26	2.7	
Horse drawn	6	1	27		10.0	13	1.3	.22
	7	3	23		8.7	11	1.3	.19
	8	22	28		9.5	17	1.8	.23
All horse drawn		26	28		9.4	16	1.7	

BARLEY

Combine:								
Tractor drawn, with power take-off	8	1	32		8.0	12	1.5	0.19
	10	9	24	2.9	9.0	18	2.0	.20
Tractor drawn, with auxiliary engine	9	4	29	2.5	9.3	14	1.5	.17
	10	9	28	2.7	9.5	20	2.1	.21
	12	11	25	2.7	8.8	23	2.6	.22
All tractor drawn		34	26	2.7	9.1	20	2.2	
Binder:								
Tractor drawn	10	1	35		10.0	33	3.3	.33
Horse drawn	8	1	24		9.0	14	1.5	.19

TABLE 10.—*Acres of specified crops cut per day, per hour, and per foot of width by combines and binders of different types and widths*—Continued

SOYBEANS

Type of machine	Width of cut	Machine	Yield per acre	Rate of travel	Length of day	Cut per day	Cut per hour	Cut per hour foot of width
	Feet	*Number*	*Bushels*	*Miles per hour*	*Hours*	*Acres*	*Acres*	*Acres*
Combine:								
Tractor drawn, with power take-off	8	5	14	2.4	6.1	7	1.2	0.15
	10	23	14	2.7	6.4	14	2.2	.22
Tractor drawn, with auxiliary engine	9	4	15	2.6	6.1	10	1.6	.18
	10	24	16	2.8	6.0	12	2.0	.20
	12	8	14	2.5	6.7	14	2.1	.18
All tractor drawn		64	14	2.7	6.1	12	2.0	
Binder:								
Horse drawn	7	1	8		6.5	5	.8	.11
	8	1	12		7.0	15	2.2	.28
All horse drawn		2	11		6.7	10	1.5	

CLOVER

Combine:								
Tractor drawn, with power take-off	8							
	10	9	2.6		7.0	11	1.5	0.15
Tractor drawn, with auxiliary engine	9	1	2.0		6.8	7	1.1	.12
	10	12	3.3	1.9	6.8	12	1.7	.17
	12	5	2.7	1.7	8.7	14	1.6	.13
All tractor drawn		27	2.9	1.8	7.2	12	1.6	
Binder:								
Tractor drawn	8	1	1.6	3.0	8.0	8	1.0	.12
Horse drawn	7	1	1.0		8.0	8	1.0	.14
	8	1	1.7		8.0	10	1.2	.15
All horse drawn		2	1.2		8.0	9	1.1	

The daily acreage harvested by all machines was considerably less than the capacity of any of the different widths of machines traveling at the estimated speed per hour and working the indicated number of hours per day. For example, a machine cutting a swath of 10 feet would cover 1.21 acres in traveling a mile, and one of 12 feet, 1.45 acres. With a 10-foot auxiliary-motored combine traveling at 2.7 miles per hour in wheat (Table 10) the theoretical hourly duty would amount to 3.27 acres, and in a 9-hour day the acreage would amount to 29.43, an increase of about 55 per cent over what operators estimated was accomplished. Likewise the 12-foot machine would cut 45.46 acres of wheat, a difference of about 82 per cent. With an 8-foot horse-drawn binder the machine would cover 0.97 acre per mile, which at a rate of 2.3 miles per hour would amount to 2.23 acres per hour or 21.63 acres per day, an increase of about 27 per cent over what operators of this size binder actually accomplished.

The apparently large difference in the theoretical acreage which a machine could cover and the actual acreage covered can be accounted for in numerous ways. In actual harvesting the machine is not in constant motion at a uniform speed. Stops are made to take on fuel, oil, and water, to dump grain, to wait for a wagon or truck, and to

make minor repairs or adjustments. In addition, crop or soil conditions in certain parts of the field cause a loss of time, and finally the machines do not cut a swath of full width. In Table 11 are shown some of the factors which in part cause loss of time, with a consequent reduction in the daily acreage harvested, and the distance machines are moved from different fields.

TABLE 11.—*Distance combine or binder was moved to field and time used to keep machine in running order*

Type of machine	Width of cut	Machines	Distance moved to fields	Cutting time	Time lost from breaks	Time moving machine	Chores (man labor)—	
							On machine	On tractor used with machine
SMALL-GRAIN HARVEST								
Combine:	*Feet*	*Number*	*Miles*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
Tractor drawn with power take-off	8	8	1.8	83.3	4.4	2.4	6.7	4.8
	10	41	1.7	69.0	1.8	3.4	10.0	4.9
Tractor drawn, with auxiliary engine	9	9	2.2	66.9	.3	2.7	8.0	4.7
	10	31	1.4	75.8	4.5	2.9	9.6	3.6
	12	18	2.2	87.8	5.3	4.4	11.5	4.9
All		107	1.8	75.0	3.2	3.3	9.7	4.5
Binder:								
Tractor drawn	7	4		36.4	1.1	1.8	4.3	3.4
	8	4		33.8	3.5	1.6	2.1	1.8
	10	5		42.2	.2	2.1	3.6	1.4
Horse drawn	6	2		31.0		.6	1.4	
	7	4		47.0	6.2	2.0	2.7	
	8	24		45.9	1.5	1.4	2.2	
All		43		42.8	1.9	1.6	2.6	2.1
SOYBEAN HARVEST								
Combine:								
Tractor drawn with power take-off	8	5	1.6	54.3	1.0	2.4	4.6	3.0
	10	23	2.8	54.0	6.1	3.0	9.0	3.2
Tractor drawn, with auxiliary engine	9	4	6.3	48.6	1.1	3.9	6.2	3.2
	10	24	2.1	46.1	1.6	2.7	7.7	2.7
	12	8	2.6	46.7	1.1	5.8	7.3	3.8
All		64	2.5	50.0	3.1	3.2	7.7	3.1
Binder:								
Tractor drawn	7							
	8							
	10							
Horse drawn	6							
	7	1		16		.5	1.5	
	8	1		18	.2	.5	1.0	
All		2		17	.1	.5	1.2	
CLOVER HARVEST								
Combine:								
Tractor drawn with power take-off	8							
	10	9	2.0	18.5	0.4	0.9	3.1	1.3
Tractor drawn, with auxiliary engine	9	1	4.4	36.0			7.5	2.8
	10	12	3.4	22.2	.3	2.1	3.8	1.3
	12	5	3.8	43.7	1.2	4.4	6.1	3.9
All		27	3.5	25.1	.5	2.1	4.0	1.8
Binder:								
Tractor drawn	7							
	8	1		24		1.5	.2	
	10							
Horse drawn	6							
	7	1		12			.2	
	8	1		4				
All		3		13.3		.5	.1	

Examination of the performance of individual machines shows that many operators are obtaining through their efforts what might be considered a maximum daily performance from their harvesting equipment.

CONDITION OF CROP AT HARVEST TIME

LODGING

Lodging was the cause of some difficulty in harvesting several crops. Lodging was reported in Illinois by 36 farmers who grew wheat, 30 who grew oats, 9 who grew barley, and 23 who grew soybeans. Most of the lodging occurred after the crop was mature; the plants leaned or broke over as a result of wind, rain, or the weakening of the stems. The oats and barley lodged or broke over soon after maturity, whereas the wheat stood for a considerable period. Some varieties of soybeans lodged badly; others remained erect.

Eighty-nine combine owners gave their opinions regarding the comparative merits of combines and binders in handling lodged grain. Sixty-seven considered the combine better than the binder, 20 considered them equally effective, and only 2 considered the binder better than the combine for this purpose. Fifty-eight operators cut a full swath with the combine in lodged grain, but 11 cut less than a full swath. The rate of travel frequently was reduced when cutting lodged grain; about half of the operators reported a slower speed. One combine operator cut the grain in one direction only on account of lodging.

WEEDS AND UNDERGROWTH

Undergrowth, consisting chiefly of weeds and sweetclover, interfered with harvesting to some extent. The difficulties were increased when the crop was lodged or the harvesting delayed until many weeds were so tall that they could not be missed by the cutter bar. Weeds or clovers that were high enough to be cut off in harvesting interfered in several ways. The chief interference was the choking of the threshing mechanism of the combine, usually in the grain or tailing elevators. Several operators found the machine pulled harder in weedy fields. Other operators objected to the increase in the moisture in weedy grain, or the presence of weeds in the threshed grain, or the difficulty in cleaning the grain. Much grain was wasted in weedy fields either because the crop was cut high to avoid the weeds or because the grain was carried out with the mass of weed material at the rear of the separator. Parts of some fields were not cut because of heavy weed growth. Practically all the grain in fields cut with binders was shocked before weed growth interfered.

Weeds were found in nearly all crops, in sufficient number and of sufficient size to affect the harvesting and threshing with the combine to some extent. Of 83 farms in Illinois and Indiana, 40 reported weeds in wheat, 42 in oats, 8 in barley, 19 in soybeans, and 2 in clovers.

SHATTERING

Shattering of the grain or seeds due to long standing in the field was scarcely apparent. Fifty-three operators found no shattering in any crop, 31 reported light shattering in some crop or crops, and 1 soybean grower reported a loss of 2 bushels per acre from shattering. Damage to the combined crop from storms, including hail, rain, and wind, was not serious in 1927. The crop on 15 farms suffered slight damage from storms; 82 operators reported no damage. Only 17 of the 81 farmers reporting carried insurance on their crops.

RELIABILITY OF COMBINES AND BINDERS

Combines must be reliable in order to be successful. Crops for combining are left standing a considerable time after they are ripe and any further delay in harvesting increases the risk of losses from storms. The chief cause of delays following breakdowns is the necessity of waiting for new parts to arrive. One operator who was harvesting soybeans with a combine suffered a loss of 12 days following a breakdown, and another farmer was delayed 2½ days by a broken binder during wheat harvest. Except for these instances, the loss of time due to breakdowns was not serious. The average time lost from breakage during the seasons by 107 combine operators in cutting small grain was 3.2 hours. Sixty-four operators cutting soybeans lost an average of 3.1 hours from breakage and 27 operators cutting clovers lost an average of 0.5 hour from breakdowns of their combines. The average time lost from breakage to binders was 1.9 hours by 43 machines cutting small grain, 0.1 hour by 2 machines cutting soybeans, and no lost time for 3 binders cutting clovers.

More time was lost from breakage by those who used combines than by those who used binders, but the average difference was less than 2 hours for the entire season. As the combines cut larger acreages and did both the harvesting and threshing operations, they had more parts to break. When the possible delays in the threshing of crops cut with the binder are considered the combine is shown to be nearly as reliable a harvesting machine as is the binder. Less delay from breakage will be encountered when combines become so numerous that local dealers carry a full line of spare parts.

HARVESTING AND THRESHING LOSSES

The average percentage losses sustained in harvesting and threshing wheat, oats, and soybeans with combines and with binders and separators in Illinois and Indiana in 1927 are shown in Table 12. A few records of combines harvesting oats were obtained but since complete determinations of the losses in harvesting oats with a binder and threshing them with a separator were not made, a comparison of methods is not possible in the case of this crop.

TABLE 12.—*Average losses in harvesting and threshing wheat, oats, and soybeans with combines or with binders and separators, in Illinois and Indiana in 1927*

Type of loss and machine	Wheat				Oats				Soybeans			
	Illinois		Indiana		Illinois		Indiana		Illinois		Indiana	
	Fields	Loss	Fields	Loss	Fields	Loss	Fields	Loss	Fields	Loss	Fields	Loss
	No.	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*
Harvesting loss:												
Combines	27	6.6	17	3.0	2	8.8	5	9.0	12	9.9	7	15.6
Binders	12	3.6	9	2.8	-------	-------	-------	-------	-------	-------	3	20.3
Threshing loss:												
Combines	27	2.6	15	.5	2	2.9	5	2.5	12	1.8	5	1.0
Separators	12	1.5	4	.8	-------	-------	-------	-------	-------	-------	1	2.3
Total loss:												
Combines	27	8.8	-------	3.5	2	11.6	5	11.3	12	11.4	-------	16.6
Binders and separators	12	5.1	-------	3.6	-------	-------	-------	-------	-------	-------	-------	22.6

The procedure used in determining harvesting and threshing losses with small grains in Illinois was somewhat different from the method used in Indiana.

In Illinois a small pea and bean thresher was remodeled and mounted on an auto trailer. This thresher was hauled into each field and used for threshing and cleaning the straw caught behind the machines and the heads that were picked up from the stubble or shock bottoms. The yields were determined by weighing the grain, usually from 1 to 2 pecks, threshed from the same measured area in which the threshing loss determination was made. These areas were measured lengths of a swath of known width. Harvesting losses were measured by gathering up and threshing the heads left in 12 square-yard areas in the same part of the field in which the threshing losses were determined. Most of the loss tests in Illinois were repeated two to four times, and adjustments of the machines were made between the tests.

The threshing losses were measured in two parts: (1) Grain left in the heads which was recovered by threshing the straw and heads; and (2) loose grain which was recovered from the chaff after passing through the small thresher. The latter losses were by far the more important. Of the total threshing losses the portion due to grain left in the heads was 29 per cent in combine threshing and 17 per cent in separator threshing. In terms of the total crop the losses from wheat left in the head were equivalent to 0.76 per cent for the combine and 0.26 per cent for the separator. The higher losses from the combine were the result of threshing tougher grain and (frequently) to poorer adjustment.

The losses in Illinois were somewhat higher in the case of both methods of harvesting wheat than in Indiana, the losses averaging 8.8 per cent for combines and 5.1 per cent for binders and separators. Part of this difference was due to the method of determining the threshing losses. The total and threshing losses probably should be increased by about 0.75 per cent for combine threshing and 0.25 per cent for separator threshing in Indiana in order to be comparable with the determinations in Illinois.

The methods used in Indiana were as follows: The number of heads and the weight of grain in them were determined in twelve ¼-square-rod areas selected at random in each field. In fields cut with a binder the losses in each shock bottom and the number of shocks per acre also were measured. The percentage losses were calculated from yields per acre determined by harvesting the heads and weighing the threshed grain from twenty-four 4-foot sections of drill rows taken at random previous to harvest in the portion of the field in which the loss counts were made later. The threshing loss determinations were made independently of the harvesting loss measurements and not always on the same farms. The threshing losses were determined by catching the straw and chaff from a combine or separator on a canvas, while a known quantity of grain, usually 2 to 8 pecks, was being threshed, and then by winnowing the straw and chaff until the grain carried over the rear of the machine was clean enough to be measured. Only a small portion of the grain left in the heads was recovered in this way, but as a rule the losses from this source were small.

In Indiana the average losses were nearly the same in harvesting and threshing wheat by the two methods, being about 3.5 per cent for combines and 3.6 per cent for binders and separators. Conditions

were favorable for both methods of harvesting through the season. The plants in some of the wheat fields were leaning or nodding when cut with the combine but usually were sufficiently erect to be harvested readily.

The higher losses in both harvesting and threshing with the combines in Illinois are the result of the greater prevalence of lodged and broken stalks in the wheat fields of that State. Many of the heads on or near the ground were missed by the cutter bar or were cut off and dropped to the ground. The lodged and leaning stalks also necessitated lower cutting with a consequent large bulk of straw to be carried through the threshing portion of the combine. The increased quantity of straw overloaded the straw racks, chaffer, and sieves, and carried over some grain. The average losses in the two States in harvesting and threshing wheat, after correcting the Indiana results, are about 6.5 per cent for the combine and 4.5 per cent for the binder and separator.

Harvesting losses with combines when used in wheat in Indiana ranged from 0.5 to 8.4 per cent and in Illinois from 0.6 to 17.6 per cent on individual farms. Threshing losses with combines ranged from 0.2 to 1.4 per cent in Indiana and from 0.4 to 6.6 per cent in Illinois.

The average harvesting losses exceeded the threshing losses regardless of the method of harvesting, the locality, or the crop grown. Most of the harvesting loss when cutting with the binder is from heads left in the shock bottoms and at the place where the bundles are dropped on the ground. The chief harvesting losses when cutting wheat with the combine are from heads cut and dropped on the ground or thrown out by the reel. Less than 30 per cent of the heads left in the wheat fields harvested with the combine in Indiana were on short or lodged stalks missed by the cutter bar.

The losses in harvesting oats with the combine are high in both States because 60 to 100 per cent of the crop was lodged or broken over in all fields cut, and many green weeds were growing up through the lodged crop. Clean erect oats can be successfully harvested with the combine with very little loss.

Soybean losses were determined by counting the pods and beans left on 12 square-yard areas in a field. The number of beans per pod and per pound were determined from the yield samples. Yields in Indiana were determined from samples of ten 4-foot sections of rows taken at random in the field. Yields in Illinois were determined from the quantity of seed threshed while a measured area was being harvested.

The average losses in harvesting soybeans with combines and binders in Illinois and Indiana are shown in Table 12.

The average total losses in harvesting soybeans with combines were 16.6 per cent in the fields in Indiana and 11.4 per cent from 12 fields in Illinois. The fields cut with binders and threshed from the shock in Indiana showed an average loss of 22.6 per cent. The total losses included the shattering which occurred before harvest but only 2 of the fields in which the combine was used in Indiana and 3 of the 12 fields in Illinois showed any shattering. The shattering loss did not exceed one per cent except in some parts of one field in Indiana, where 20 per cent of the beans were shattered.

Beans were shattered from the vines by the reel and cutter bar, but the chief losses during harvesting were from pods on low and lodged

branches that were missed by the cutter bar. The soybeans were lodged considerably in many fields. As the cutter bar could not cut lower than 3 to 5 inches from the ground, the pods below these heights were missed. Threshing losses with combines in Indiana varied from 0.5 to 2.2 per cent and in Illinois from 0.3 to 6.5 per cent.

SAVING STRAW

Farmers consider that the chief disadvantage of combine harvesting in Illinois and Indiana is the lack of straw for feed and bedding. On combine farms where there is need for a considerable tonnage of straw, one of several methods may be employed to obtain it. The combine may be equipped with a buncher which catches all straw and chaff from the combine, the straw spreader being removed. (Fig. 4.) When the buncher is full the combine operator dumps the straw in a

FIGURE 4.—A 10-foot combine equipped with a buncher. When the buncher is full the operator dumps the straw in a pile. After harvest the straw is hauled

pile on the field. After harvest the straw is hauled in or baled in the field. Another method is to remove the straw spreader which allows the straw to fall in a windrow. Later a hay loader is used and the straw picked up and loaded onto a hayrack or delivered direct to a baler. (Fig. 5.) Where the latter method is used the baler is equipped with a gas engine and the whole outfit pulled by a tractor. Other methods employed are to rake the stubble or mow the stubble before raking, following which the straw is handled in one of the above-mentioned ways.

COSTS OF HARVESTING AND THRESHING

The direct or out-of-pocket expense for harvesting with a combine includes the cost of labor, use of tractor, repairs, fuel, oil, and grease; for harvesting with a binder and threshing with a stationery separator the direct expense includes the cost of labor, use of horses or tractor, repairs, fuel, oil, grease, and the commercial rate for threshing. The

fixed charges to be made against either harvesting machine are those of depreciation, interest, housing, taxes, and insurance.

LABOR

The number of men in the operating crew is well standardized for the different types of both machines. The power-driven combines can be operated by one man who drives the tractor, but the auxiliary motored outfits require two men—one on the tractor and one on the combine. Some operators, if plenty of help is available, use three men. The third man seldom rides with the outfit, but acts as a helper when the machine is stopped to unload grain, to take on fuel, oil, and

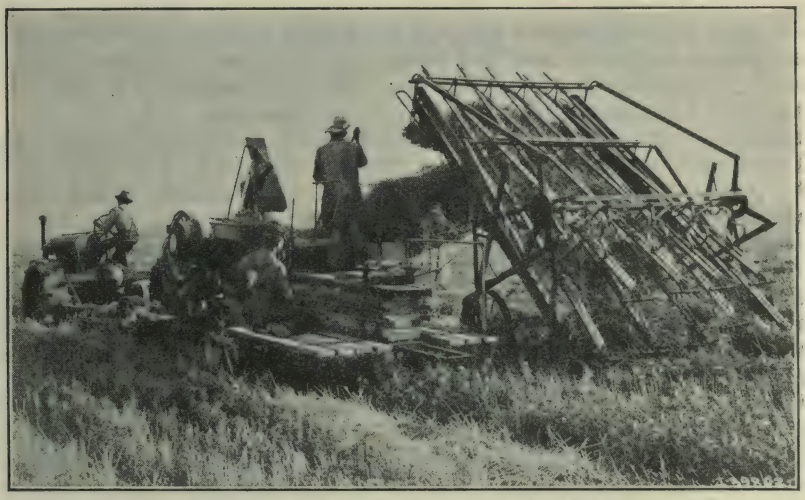

FIGURE 5.—Baling straw that had been dropped in the windrow by a combine

water, or to make repairs and adjustments. Horse-drawn binders use only one man, but some of those pulled by a tractor use two. Nearly all the power take-off binders use one man, who drives the tractor.

TABLE 13.—*Number of machines using crews of different sizes, including labor for shocking*

Type of machine	Width of cut	Machines	Number using crew of—				
			1 man	2 men	3 men	4 men	6 men
	Feet	*Number*					
Combine:							
Tractor drawn, with power take-off	8	8	7	1			
	10	41	8	32	1		
Tractor drawn, with auxiliary engine	9	9		9			
	10	31	2	27	2		
	12	18		16	2		
All		107	17	85	5		
Binder:							
Tractor drawn	7	4			1	3	
	8	4			2	2	
	10	5			1		4
All tractor drawn		13			4	5	4
Horse drawn	6	2		1	1		
	7	4			4		
	8	24		4	14	6	
All horse drawn		30		5	19	6	

The labor used on different types and sizes of combines and binders and for shocking after binders is shown in Table 13.

Of the two sizes of power take-off combines intended for operation by one man, seven of the eight operators of the 8-foot machines used only one man and the other used two. On the other hand, 32 owners of the 10-foot size used 2 men and 1 used 3. Thus only eight outfits were operated by the size of crew for which they were intended.

For the auxiliary-motored outfits the crew most commonly used consists of two men; one drives the tractor and the other looks after the combine. All of the operators of the 9-foot outfits used 2-man crews. Of the 10-foot machines, 27 were operated by 2 men, 2 by 3 men, and 2 by only 1 man. The two outfits that used only one man each were formerly power take-off machines that did not have sufficient power originally and had later been equipped with an auxiliary motor. Machines so equipped can still be operated by one man because the position of the controls is not changed.

Sixteen of the 12-foot machines used 2 men, and 2 used 3 men. On all machines using three men the third is classed as a helper whose duty it is to haul fuel, oil, water, and grease and make himself useful when the machine stops for any reason.

In each case the horse-drawn binder was operated by one man which is the universal practice except in the Eastern States where two men are used, one of whom rides one of the horses. One-half of the men who used tractors to draw their 7 and 8 foot binders used an extra man who rode the binder. With one exception each of the five men with power take-off binders handled his outfit alone.

Ordinarily, two shockers are enough to keep up with a horse-drawn binder. The majority of men who operated both types of binders (with the exception of the 10-foot outfits) used this number. Four operators of 10-foot outfits used four and one used five shockers. The speed and width of swath of these machines accounts for the larger number of shockers required.

From the difference in the size of crew used in combining and in binding and shocking, it is obvious that the use of a combine allows the operator to reduce his hired-labor requirements considerably. This is an important consideration with many farmers who have little family labor available or who find it difficult to obtain hired labor. Information from the combine owners shows that 86 per cent of the men used unpaid family labor. This labor was furnished by the farm owner and his sons. Even in the Great Plains, where most operators are young men and little family help is available, 53 per cent of the men interviewed did not use outside labor. But independence from transient labor in the Corn Belt is not the important consideration that it is in the Great Plains.

Table 14 shows the paid and unpaid labor used on the combines and on the binders.

TABLE 14.—*Paid and unpaid labor on combines and binders*

Type of machine	Width of cut	Machines	Number of outfits using—								
			Tractor operator		Machine operator		Helpers				
			Paid	Unpaid	Paid	Unpaid	Paid		Unpaid		
Combine:	*Feet*	*Number*									
Tractor drawn, with power take-off.	8	8	------	8	------	1	------		------		
	10	41	8	33	3	39		1	------		
Tractor drawn, with auxiliary engines.	9	9	1	8	------	9	------		------		
	10	31	8	23	3	26	------			2	
	12	18	4	14	------	18		1		1	
All combines	------	107	21	86	6	84		2		3	
							Shockers				
							1 man	2 men	3 men	4 men	5 men
Binder: Tractor drawn	7	4	------	4	------	2	------	3	1	------	------
	8	4	------	4	------	2	------	4	------	------	------
	10	5	------	5	------	1	------	1	------	1	3
All tractor drawn	------	13	------	13	------	5	------	8	1	1	3
Horse drawn	6	2	------	------	------	2	1	1	------	------	------
	7	4	------	------	------	4	------	4	------	------	------
	8	24	------	------	------	24	4	14	6	------	------
All horse drawn	------	30	------	------	------	30	5	19	6	------	------

In the case of combining, most of the hired help was used on the tractor as the majority of the owners preferred to run their own combines. The class of labor hired for combine operation is of a higher grade than that used for harvesting with a binder; it naturally follows that the combine operator should expect to pay a higher daily wage than does the neighbor who is hiring a shocker.

The economy in the use of man labor is shown by a comparison of man-hours per acre for different methods of harvesting. Where a binder is used and wheat is cut, shocked, and threshed from the shock, the labor per acre is about 3.6 man-hours, as compared with about 0.78 man-hour for harvesting with a 10-foot auxiliary motored combine.

This comparison includes only the labor of cutting, shocking, and hauling bundles to the thresher furnished by the farmer and does not include the labor furnished by the thresherman. The cost of this threshing labor is included in the rate paid by the farmer for threshing. For the combine, the labor includes the tractor driver, the combine operator and the helper, if any. The labor of hauling grain is not included in either case. To obtain the total saving in labor, approximately 0.83 hour per acre for threshing should be added to the figure given for harvesting with either a binder or a header. A machine operated by a crew of 5 pitchers and 3 machine men, and threshing 1,200 bushels in a 10-hour day, would be equivalent to 1 man-hour labor per acre in wheat that yields 18 bushels an acre.

The total labor for harvesting and threshing is reduced from approximately 4.43 man-hours for cutting with a binder and threshing with

a stationary thresher, to about 0.78 man-hour an acre in cases where the work is done with a 10-foot auxiliary motored combine.

The crew to operate a combine is smaller than that for cutting grain with a binder and for shocking. For grain acreages of over 200, when more than one binder would be needed, a combine would reduce the size of the harvest crew still further. The use of the combine also eliminates the crew necessary for stationary threshing.

The labor used for hauling grain from a combine or stationary thresher is dependent upon a number of conditions and varies on different farms. The number of haulers necessary will depend on the distance the grain is hauled, the hauling equipment, the method of loading and unloading, and the quantity of grain threshed per day.

Where combines are used and the grain is stored in a farm bin, one man and team can usually take care of the grain providing the distance

FIGURE 6.—The labor for hauling is lowest when grain is hauled by truck from the combine

hauled is short and a portable elevator is used. If, as is a common practice, the load is scooped into the bin, two or more men are required. When only one team is used, the grain is usually run into a wagon pulled along with the combine. The use of both teams and trucks for hauling on the same farm indicates that the horses are being used largely to haul grain to the bins for storage or to supplement the trucks on the longer hauls to town.

The majority of the combine operators use two or more teams for hauling grain to town if no truck is used. The smallest amount of labor is necessary for hauling when a truck is used, and the combine is equipped with a grain tank that allows the grain to run directly into the truck (fig. 6), and the truck is unloaded by dumping. The time required for a round trip is shorter if a truck is used, and practically all operators can get along with only one helper. A combine that is not equipped with a grain tank sometimes requires a larger

hauling crew as the grain is run directly into a wagon attached to the machine. If a truck is used for hauling, the grain must be scooped into it and this requires an extra man or two.

The average distance to the bin on the farms that harvested with a combine was approximately one-half mile; the distance to town averaged about 3 miles.

It is estimated that a combine equipped with a grain tank and harvesting 800 bushels of wheat per day, requires the full time of one 60 or 65 bushel truck to haul grain to an elevator 5 miles distant.[3]

The number of combine operators who used horses exclusively for hauling was 56, and the number who used trucks exclusively was 20, and the remaining 31 used both horses and trucks. Of the men

FIGURE 7.—Some men who are using horse binders for harvesting are pulling the machines with a tractor

using horses, only 38 found that 2 teams were necessary for hauling; of those using trucks exclusively, 12 found that 1 truck was sufficient to handle the grain.

In hauling grain from a stationary threshing machine, whether to the bin or to town, the large majority of operators use two haulers and teams and a few use a third man to help scoop the grain into the bin. If the grain is hauled by truck the majority of men use only one outfit but a few use two trucks to eliminate scooping from wagons to the truck for each load hauled. Others use both a truck and horses.

If only one team is available to haul grain from a stationary thresher, the haul must be short and to the farm bin, and there must be two wagons. If only one truck is available for hauling, the haul should be comparatively short for the grain must be scooped from wagons at the machine into the truck for each trip. Among these farms, the distance between the stationary thresher and the bin averaged about 50 rods, and the distance to town averaged slightly less than 4 miles.

POWER

In each instance the combine owner used a tractor to furnish the power for operating the machine. The majority of the binders were pulled by horses, but a number of power binders were operated with

[3] REYNOLDSON, L. A., KIFER, R. S., MARTIN, J. H., and HUMPHRIES, W. R. Op. cit., p. 24.

tractors, and a few men used tractors to pull their old horse-drawn machines. (Fig. 7.) The charge for the power furnished by the tractor for combining or binding is dependent upon the size of the tractor and the yearly amount of other work which is done with it. As both the tractors and horses were used for other work on all farms, the most equitable charge for power is on the acre basis. Based on the hourly charge as used by the Illinois Agricultural Experiment Station in the preliminary publications on combine studies for that State, a charge of 36 cents per acre is the rate fixed for the power furnished by tractors. For horse labor based on studies for the same station a charge of 13 cents per hour, or 54 cents per acre, is the rate fixed for operating a binder and threshing. The tractor charge can be applied to any size machine providing the given tractor is about the size necessary to pull the given size combine. Although a large tractor would be used on a large combine and a small tractor on a small combine, the acreage covered by each would be proportionate to the size of the combine.

FUEL AND LUBRICANTS

The fuel and lubricants used in tractors and auxiliary engines in combine harvesting of different crops are shown in Table 15. Gasoline or gasoline and kerosene, was used as a tractor fuel by all operators. For the auxiliary engine with which many of the machines were provided, gasoline was used exclusively. The quantity of fuel and lubricants used per day or hour by tractors varied according to the size of the machine, but tractors of the same size sometimes use different quantities, and individual operators may use more or less fuel and lubricants in similar machines. Further differences are caused by the condition of the engine, yield and kind of grain, and the rate of travel. The same variation occurs in the quantity of fuel and lubricants used in the auxiliary engine but to a lesser degree than in the case of the tractor. One fuel has no advantage over the other in the amount of work accomplished per gallon, consequently kerosene is used because it is the cheaper fuel.

The tractors on the power take-off outfits use more fuel than do those pulling a combine operated by an auxiliary engine. However, the total quantity of fuel and lubricants used by the latter type machines is greater than that used by the former for practically all crops and sizes of machines. Because of the narrow range in the size of combines used in the Corn Belt as compared with those used on the Great Plains, little comparison can be made in the quantities of fuel used by large and by small machines per acre. For the auxiliary-motored machines there is little difference in the fuel requirements for the different crops, but for the power-take-off outfits the requirements are higher for soybeans and barley than for any other crop. The variation in the quantities of lubricants used in tractors and auxiliary engines with combines of the indicated types and sizes during this study was slight. The greatest range in oil used per acre for auxiliary-motored outfits was 0.03 gallon and for the power take-off outfits 0.04 gallon. The quantities of grease used by both types were small.

For harvesting with a tractor-drawn binder the quantities of fuel and lubricants used by the tractor do not differ greatly from the quantities used by tractors on power take-off combines. Total quantities of fuel and lubricants used per acre or per bushel for harvesting

TABLE 15.—*Fuel and lubricants used in tractor and auxiliary engine for different crops*

Kind of crop	Type of combine	Width of cut	Combines	Area cut	Grain threshed	Fuel and oil used per outfit											
						Fuel					Oil			Grease			
						Gasoline	Kerosene	Total	Per acre	Per bushel	Total	Per acre	Per bushel	Total	Per acre	Per bushel	
		Feet	*Number*	*Acres*	*Bushels*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Pounds*	*Pounds*	*Pounds*	
Wheat	Tractor drawn, with power take-off.	8	8	71	1,236	59	38	97	1.37	0.079	4	0.06	0.003	6	0.08	0.005	
		10	39	100	1,646	42	94	136	1.36	.083	5	.05	.003	10	.10	.006	
	Tractor drawn, with auxiliary engine.	9	8	77	1,460	97	45	142	1.84	.097	6	.08	.004	3	.04	.002	
		10	29	99	1,754	107	45	152	1.53	.087	6	.06	.003	10	.10	.006	
		12	17	117	2,182	157	39	196	1.67	.090	8	.07	.004	9	.08	.004	
	All combines		101	99	1,720	85	63	148	1.50	.086	6	.06	.003	9	.09	.005	
Oats	Tractor drawn, with power take-off.	8	7	50	1,401	24	47	71	1.42	.051	2	.04	.001	4	.07	.003	
		10	28	59	1,473	37	43	80	1.35	.054	3	.05	.002	6	.10	.004	
	Tractor drawn, with auxiliary engine.	9	8	58	1,744	64	30	94	1.60	.054	5	.08	.003	1	.02	.001	
		10	23	76	2,077	91	23	114	1.50	.055	4	.05	.002	8	.10	.004	
		12	16	80	2,838	92	29	121	1.51	.043	6	.08	.002	5	.06	.002	
	All combines		82	67	1,929	64	34	98	1.46	.051	4	.06	.002	6	.09	.003	
Barley	Tractor drawn, with power take-off.	8	1	72	2,340	123		123	1.71	.053	6	.08	.003	4	.06	.002	
		10	9	56	1,356	43	51	94	1.69	.070	3	.05	.002	6	.10	.004	
	Tractor drawn, with auxiliary engine.	9	4	16	467	15	19	34	2.14	.073	1	.08	.003	1	.05	.002	
		10	9	40	1,100	46	4	50	1.26	.045	2	.05	.002	4	.10	.004	
		12	11	79	1,972	110	10	120	1.52	.061	5	.07	.003	6	.07	.003	
	All combines		34	55	1,412	65	20	85	1.54	.060	3	.06	.002	4	.08	.003	
Soybeans	Tractor drawn, with power take-off.	8	5	66	934	84	35	119	1.81	.127	4	.06	.004	5	.08	.006	
		10	23	120	1,639	110	56	166	1.39	.101	5	.04	.003	14	.12	.009	
	Tractor drawn, with auxiliary engine.	9	4	76	1,115	134	4	138	1.80	.124	5	.07	.005	1	.02	.001	
		10	24	93	1,446	109	33	142	1.53	.098	6	.06	.004	12	.13	.008	
		12	8	99	1,384	131	25	156	1.57	.113	7	.07	.005	6	.06	.004	
	All combines		64	100	1,447	112	38	150	1.50	.104	6	.06	.004	11	.11	.008	
Clover	Tractor drawn, with power take-off.	10	9	28	72	5	33	38	1.35	.531	2	.07	.027	2	.08	.034	
	Tractor drawn, with auxiliary engine.	9	1	38	75	19	30	49	1.29	.653	10	.25	.127	1	.03	.013	
		10	12	34	112	38	16	54	1.57	.480	3	.09	.029	4	.12	.036	
		12	5	71	193	135	19	154	2.17	.795	4	.06	.020	2	.03	.011	
	All combines		27	39	113	44	23	67	1.71	.595	3	.08	.028	3	.08	.027	

with a binder and threshing with a stationary thresher run higher than for combine harvesting. No comparisons are made, however, in Table 15, because much of the fuel used for stationary threshing was coal.

THRESHING

The cost of threshing small grain constitutes a considerable part of the total cost of harvesting and threshing with a binder and stationary thresher. In combining, although a certain amount of the total cost is chargeable to threshing, it is not a separate item as is that for stationary threshing. What the cost for threshing will amount to is dependent primarily upon whether the threshing outfit is custom or cooperatively owned. The majority of the men interviewed who owned binders had a partnership in a cooperatively owned threshing machine; consequently their grain was threshed at less expense than if they had hired a custom outfit, as there was no profit to pay.

REPAIRS

The first combine used in Illinois was purchased in 1924, and as shown in Table 3 all of the machine owners interviewed in this study had purchased their outfits in 1926 or later. Only about one-fifth of the combines had operated through two harvest seasons and the remainder were in their first year. During the first year of operation repairs are usually furnished free if the broken part shows defective material or workmanship. Actual yearly repair expense for these Corn Belt machines would be higher than the average shown, because the longer a machine is used the greater the repair expense becomes.

On the 107 combines used, operators reported an average repair charge of $3 a machine, and there was an average of 0.3 day of expert man labor required to repair or adjust the machine for harvesting. The average age of these machines was only 1.2 years, which accounts for the low repair and man-labor charge. Combines operating in the Great Plains, with an average age of 2.4 years, or exactly twice the age of the Corn Belt outfits, had an average repair cost of $20 for the season and required 2 days of expert labor for repairs.[4] However, combines in the Great Plains harvest over twice the acreage annually harvested by those in the Corn Belt.

Results in the Great Plains indicated that on the combines which have been in use for about one-half of their expected life of 8 years the cash cost of repairs is about 10 cents an acre. For computing harvesting costs in the studies which have been made heretofore an allowance of 10 cents an acre has been made for the purchase of yearly repair parts on the combine.

Table 16 shows the average cost of repairs and the expert labor requirements, by size and age of machine.

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[4] REYNOLDSON, L. A., KIFER, R. S., MARTIN, J. H., and HUMPHRIES, W. R. Op. cit., p. 28.

TABLE 16.—*Average cost of repairs and expert labor requirements*

Type of machine	Width of cut	Machines	Age of machine	Cost of repairs	Expert labor on repairs
Combine:	*Feet*	*Number*	*Years*	*Dollars*	*Days*
Tractor drawn, with power take-off	8	8	1.1	3	0.4
	10	41	1.2	5	.3
Tractor drawn, with auxiliary engine	9	9	1.0	1	.2
	10	31	1.1	3	.2
	12	18	1.4	3	.4
All combines		107	1.2	3	.3
Binder:					
Tractor drawn	7	3	23.7	11	.2
	8	4	10.5	4	0
	10	5	2.8	1	0
Horse drawn	6	2	23.5	0	0
	7	4	8.8	4	0
	8	23	10.0	3	0
All binders		41	10.7	3	

Repairs on the 41 binders for the same year also showed an average charge of $3 each. In proportion to the first cost of a binder this repair charge is seven times higher than for the combines. The average age of all binders for which the above figure was obtained is 10.7 years, which would give a very reliable yearly repair figure. For the power binders, the oldest of which was only 4 years, the average annual repair charge was $1 each. On the other hand the two 6-foot binders, one of which was purchased in 1897 and the other in 1912, had no repairs for the year. Long experience in the care and repairs is indicated by the fact that practically no expert labor was employed for repairing the binders. Only one operator of a 7-foot machine required such assistance. It is probable that in a short time many owners of combines will become so familiar with their machines as to require little, if any, expert labor for repair.

Most of the tractors used with the combines and binders were purchased primarily for other work, but certain repair and labor costs are chargeable to the cost of operating these machines. To prorate these costs is difficult, as there are many variables. What part of these costs to charge to harvesting, when repairs are necessary shortly after harvest begins or at the beginning of another job following harvest, is questionable. Lack of data precludes the fixing of a yearly or acre charge for these costs. Perhaps the most equitable charge would be based on the total yearly acreage covered by the tractor. The total yearly repair and labor costs, divided by the total acreage over which the tractor was used, would give a per-acre charge which could be made against the tractor for each acre harvested.

SHELTER

In the Corn Belt it is the general custom to shelter most farm machinery when not in use. Even farmers who do not shelter all their machinery usually make an effort to house their combines, since these machines cost more than any other single item of farm equipment. Of the 107 combine owners, 79 housed their machines. Based on the estimates of these men, the annual charge for shelter amounted to $12. In some instances the operator had built a shed for the com-

bine, but a majority stored their machines in the machine shed. As most of the unsheltered machines were new, it is possible that housing will be provided for many.

All the binder operators housed their machines at a reported annual cost of $5 each.

FIRST COST AND DEPRECIATION

The high first cost of combines is an obstacle which may prevent some farmers who have acreage sufficient to harvest with it from purchasing a machine. Even considering the greater convenience in harvesting and the elimination of much of the harvest labor required when a binder is used, the original outlay and the high charges for depreciation and interest are more than some men are in a position to afford. The first cost of binders, including the power-driven outfits, which are more expensive than are the horse-drawn machines, is but one-seventh that of the average combine in the Corn Belt. If a tractor is not already owned, there is the additional cost for the purchase of one to operate the combine, unless the farmer uses horses. Few Corn Belt farms have enough horses to pull a combine.

Table 17 shows the average cost of combines and binders of different types and sizes to farmers in this area and the farmer's estimate of the life of the different machines.

TABLE 17.—*First cost and expected life of combines and binders*

Type of machine	Width of cut	Machines	Average cost	Estimated life
Combine:	*Feet*	*Number*	*Dollars*	*Years*
Tractor-drawn, with power take-off	8	8	1,000	9.8
	10	41	1,107	9.6
Tractor drawn, with auxiliary engine	9	9	1,559	12.5
	10	31	1,412	8.4
	12	18	2,120	10.1
Total or average		107	1,396	9.6
Binder:				
Tractor drawn	7	3	127	24.0
	8	3	177	12.5
	10	5	281	11.4
Horse drawn	6	2	112	28.5
	7	2	140	15.0
	8	19	208	15.9
Total or average		34	199	16.2

The first cost of a binder is dependent upon the width of cut and is practically the same for all makes. The price of a combine is also dependent upon the width of cut but varies considerably according to the terms of purchase and the extra equipment bought with the machine. Combines of the power-driven type with an 8-foot cut can be bought for $1,000, whereas the largest machine used in the Corn Belt, with a 12-foot cutter bar and mounted with an auxiliary engine, costs about $2,100. Compared with an 8-foot combine, the 8-foot binders show an average cost of $204, a price somewhat lower than the prices in effect at present as some of these machines were purchased in years when prices were lower. Comparing the 10-foot sizes, the cost of a power-driven binder averages $281, a power-take-off combine $1,107, and the auxiliary type, $1,412.

Because of the comparatively short time that farmers have used combines in the Corn Belt, they have little experience upon which to base an estimate of the probable life of their machines. Estimates obtained from operators show that, on the average, the combines were expected to last nearly 10 harvest seasons. In the Great Plains the estimate was for eight seasons with an approximate 100 per cent increase in the average acreage harvested annually.

For the 107 combines and the 41 binders, depreciations, as derived from first cost, estimated life, and acres harvested annually, is 53 cents and 13 cents an acre, respectively. This charge is one of the most important costs to be considered in purchasing a combine for harvesting.

The depreciation per acre chargeable to combines and binders for different acres harvested is shown in Table 18. The charges as indicated for the various size machines cutting different acreages are based upon the assumption that there is no relation between annual acres harvested and the life of the machine. When computed in this manner depreciation charges are a fixed charge and are dependent upon the yearly acreage harvested.

TABLE 18.—*Depreciation in value of combines and binders per acre for different acreages cut*

Type of machine	Width of cut	Machines	Average cost	Yearly depreciation[1]	Depreciation per acre harvested annually									
					50 acres	100 acres	150 acres	200 acres	250 acres	300 acres	400 acres	500 acres	600 acres	700 acres
Combine:	*Feet*	*No.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
Tractor drawn, with power take-off.	8	8	1,000	100	-----	1.00	0.67	0.50	0.40	0.33	0.25	-----	-----	-----
	10	41	1,107	111	-----	1.11	.74	.56	.44	.37	.28	0.22	0.18	-----
Tractor drawn, with auxiliary engine.	9	9	1,559	156	-----	1.56	1.04	.78.	.62.	. 52	.39	-----	-----	-----
	10	31	1,412	141	-----	1.41	.94	.70	.56	.47	.35	.28	.24	-----
	12	18	2,120	212	-----	2.12	1.41	1.06	.85	.71	.53	.42	.35	0.30
Binder:														
Tractor drawn	7	3	127	8	0.16	.08	.05	-----	-----	-----	-----	-----	-----	-----
	8	3	177	11	.22	.11	.07	.06	-----	-----	-----	-----	-----	-----
	10	5	281	18	.36	.18	.12	.09	.07	.06	-----	-----	-----	-----
Horse drawn	6	2	112	7	.14	.07	-----	-----	-----	-----	-----	-----	-----	-----
	7	2	140	9	.18	.09	-----	-----	-----	-----	-----	-----	-----	-----
	8	19	208	13	.26	.13	.09	.06	-----	-----	-----	-----	-----	-----

[1] Depreciation of combines is based upon an expected life of 10 years, as determined from estimates of 107 combine owners. Depreciation of binders is based upon an expected life of 16 years, as determined from estimates of 34 binder owners.

COSTS FOR DIFFERENT ACREAGES HARVESTED

Harvesting costs differ according to difference in the prices of the factors which make up the total cost in various grain-growing sections of the country. Even in different parts of the Corn Belt there are differences caused by variations in prices of machines, wages of labor, and prices of fuel and lubricants. During the same year or over a series of years some variation in costs per acre also occurs with different crops and with differences in yields and conditions of the same crop. The variation is less when computed on the acre rather than on the bushel basis. A wide variation in acre costs also occurs on different farms under similar conditions of weather, prices, and yields. Variations in such factors as length of life of the machine, repairs, acres cut per day, and mechanical ability of the operator cause variations in costs so that computations representing averages are not applicable to individual farms, but should closely approximate the results individual

operators should expect. Table 19 shows the costs of harvesting and threshing different acreages of small grain with combines and binders.

TABLE 19.—*Depreciation and interest charges per acre for 10-foot combines and 8-foot binders for various acreages, and total costs per acre for harvesting and threshing with 10-foot combines and 8-foot binders*

Area cut annually	Depreciation and interest charges per acre for—		Total cost per acre for harvesting and threshing						
			Wheat, with—		Oats, with—		Barley, with 10-foot auxiliary-motored combine	Soybeans, with 10-foot auxiliary-motored combine	Clover, with 10-foot auxiliary-motored combine
	10-foot auxiliary-motored combine	8-foot binder	10-foot auxiliary-motored combine	8-foot binder [1]	10-foot auxiliary-motored combine	8-foot binder [1]			
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
50 acres	3.76	0.48	4.83	3.92	4.81	3.55	4.82	4.83	5.06
100 acres	1.88	.24	2.95	3.68	2.93	3.31	2.94	2.95	3.18
150 acres	1.25	.16	2.32	3.60	2.30	3.23	2.31	2.32	2.55
200 acres	.94	.12	2.01	3.56	1.99	3.19	2.00	2.01	2.24
250 acres	.75		1.82		1.80		1.81	1.82	2.05
300 acres	.62		1.69		1.67		1.68	1.69	1.92
400 acres	.47		1.54		1.52		1.53	1.54	1.77
500 acres	.37		1.44		1.42		1.43	1.44	1.67
600 acres	.31		1.38		1.36		1.37	1.38	1.61

[1] Including cost of hired separator for threshing.

The costs of harvesting with a combine and binder were computed by applying current prices to the average quantities of materials and labor used as shown in previous tables on combine and binder operations. For the combine, these costs include depreciation, interest, repairs, fuel, and oil for both the combine and tractor and a charge for all labor (exclusive of grain hauling) at going wages. For the binder, these costs include depreciation, interest, repairs, twine, all labor and horse work (exclusive of grain hauling) and a charge for threshing based on rates used for custom threshing. The factors used and the prices applied are shown in Table 20.

TABLE 20.—*Charges per acre for harvesting different crops with different methods*

Item of cost	Per acre charge on wheat				Per acre charge on oats			
	10-foot combine		8-foot binder		10-foot combine		8-foot binder	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
		Dollars		*Dollars*		*Dollars*		*Dollars*
Man labor [1]—man-hours	0.90	0.36	4.0	1.20	0.85	0.34	3.2	0.96
Horse labor [2]—horse-hours			5.3	.69			4.5	.58
Tractor		.36				.36		
Fuel [3]—gallons	1.44	.20			1.43	.20		
Oil [3]—do	.06	04			.06	.04		
Grease—pounds	.10	.01			.10	.01		
Twine [4]—do			2.0	.24			3.0	.36
Repairs		.10		.05		.10		.05
Threshing [5]				1.26				1.12
Total		1.07		3.44		1.05		3.07
	Annual charge							
Depreciation [6]	$141.20		$15.62		$141.20		$15.62	
Interest [7]	46.60		7.98		46.60		7.98	

TABLE 20.—*Charges per acre for harvesting different crops with different methods*—Continued

Item of cost	Per acre charge on barley with 10-foot combine		Per acre charge on soybeans with 10-foot combine		Per acre charge on clover with 10-foot combine	
	Quantity	Cost	Quantity	Cost	Quantity	Cost
		Dollars		*Dollars*		*Dollars*
Man labor [1]—man-hours	0.87	0.35	0.90	0.36	1.42	0.57
Horse labor [2]—horse-hours						
Tractor		.36		.36		.36
Fuel [3]—gallons	1.51	.21	1.45	.20	1.49	.21
Oil [3]—do	.05	.03	.05	.03	.06	.04
Grease—pounds	.10	.01	.12	.02	.11	.02
Twine [4]—do						
Repairs		.10		.10		.10
Threshing [5]						
Total		1.06		1.07		1.30
	Annual charge					
Depreciation [6]	$141.20		$141.20		$141.20	
Interest [7]	46.60		46.60		46.60	

[1] Labor on combine charged at 40 cents per hour; on binder at 30 cents per hour.
[2] Horse-labor charged at 13 cents per hour.
[3] Fuel charged at 14 cents, oil at 64 cents per gallon.
[4] Twine charged at 12 cents per pound.
[5] Threshing wheat charged at 7 cents per bushel for 18-bushel yield; oats, 4 cents per bushel for 28-bushel yield.
[6] Based on 10-year life for combine; 16-year life for binder.
[7] Annual charge per machine based on the average investment at 6 per cent.

FIGURE 8.—When all costs are considered, including depreciation and interest, the 8-foot binder is cheaper than the 10-foot combine if there are less than 80 acres to harvest.

With depreciation and interest included in costs, a large investment in machinery causes a high harvesting charge per acre when a small acreage is cut. Depreciation charges are based on an estimate of 10 years for the life of the combine and 16 years for the binder

irrespective of the annual acreage cut. In actual practice it is probable that the yearly depreciation would be less for machines harvesting small acreages than for those harvesting large acreages. On farms in which high or very low annual acreages are cut the amount of work done would affect the length of service of both types of machines.

For 50 acres of wheat or oats a year, the cost of combining with a 10-foot machine is considerably greater than is the cost of harvesting with an 8-foot binder and hiring the threshing done with a stationary separator. (Fig. 8.) For 100 acres a year the cost with the combine is somewhat less than with a binder, and for 150 and 200 acres a year there is a substantial difference in favor of the combine. For harvesting clover with a 10-foot combine the cost exceeds that for harvesting small grain or soybeans.

Table 21 shows only those factors for which there would be a cash cost for either a combine or a binder.

TABLE 21.—*Cash costs per acre incident to harvesting by different methods where the labor of two men is available and threshing labor is exchanged*

Item of cost	Per acre charge on wheat				Per acre charge on oats			
	10-foot combine		8-foot binder		10-foot combine		8-foot binder	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
		Dollars		*Dollars*		*Dollars*		*Dollars*
Extra labor [1]—man-hours	0.10	0.04	0.81	0.24	0.10	0.04	0.55	0.16
Fuel [2]—gallons	1.44	.20			1.43	.20		
Oil [2]—do	.06	.04			.06	.04		
Grease—pounds	.10	.01			.10	.01		
Twine [3]—do			2.0	.24			3.0	.36
Repairs		.10		.05		.10		.05
Threshing [4]				1.26				1.12
Total		.39		1.79		.39		1.69
Depreciation [5]		141.20		15.62		141.20		15.62

Item of cost	Per acre charge on barley for 10-foot combine		Per acre charge on soybeans for 10-foot combine		Per acre charge on clover for 10-foot combine	
	Quantity	Cost	Quantity	Cost	Quantity	Cost
		Dollars		*Dollars*		*Dollars*
Extra labor [1]—man-hours	0.10	0.04	0.10	0.04	0.10	0.04
Fuel [2]—gallons	1.51	.21	1.45	.20	1.49	.21
Oil [2]—do	.05	.03	.05	.03	.06	.04
Grease—pounds	.10	.01	.12	.02	.11	.02
Twine [3]—do						
Repairs		.10		.10		.10
Threshing [4]						
Total		.39		.39		.41
Depreciation [5]		141.20		141.20		141.20

[1] Extra labor charge on combine 40 cents per hour; on binder 30 cents per hour.
[2] Fuel charged at 14 cents, oil at 64 cents per gallon.
[3] Twine charged at 12 cents per pound.
[4] Threshing charge on wheat at 7 cents per bushel for an 18-bushel yield; oats 4 cents per bushel for a 28-bushel yield.
[5] Based on 10-year life for combine; 16-year life for binder.

ACREAGES ON WHICH COMBINES AND BINDERS WILL BE ECONOMICAL

In the Corn Belt many combines are bought with the idea of using them for harvesting crops entirely on the home farm. After purchasing, however, most farmers have found time to do some custom work for their neighbors as a means of partly paying for the outfit. Operators of the binders also do some custom work, but this is probably more for accommodation than for profit.

Figure 3 and Table 7 show that the larger size combines were used for harvesting the larger acreages, although there is a wide range in the acres harvested in 1927 by machines of different sizes, due chiefly to the influence of the amount of custom cutting. With binders, most of the custom work was done by the 10-foot power-driven outfits with a lesser amount done by men who used a tractor to pull their 7-foot horse-drawn binders. A few operators of 8-foot horse-drawn binders also did a small amount of custom work.

The minimum acreage of small grain for which combines of different sizes will be profitable is determined largely by the cost of harvest-

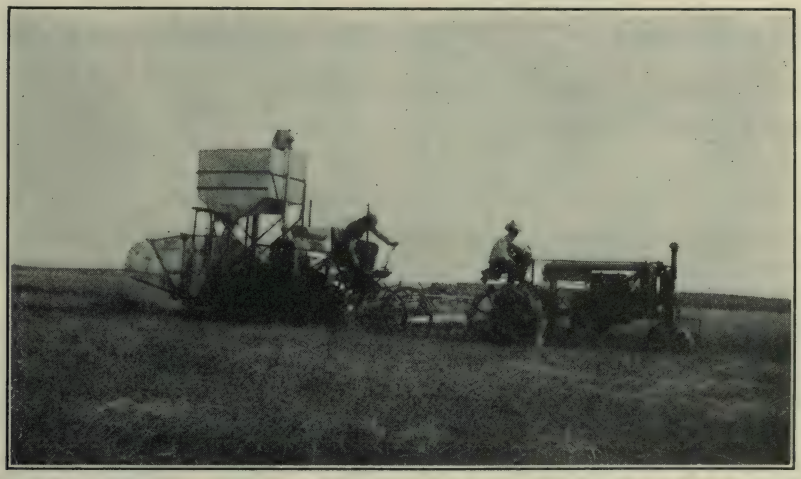

FIGURE 9.—When all costs are considered, including depreciation and interest, the 10-foot combine is cheaper than the 8-foot binder if there are more than 80 acres of crops to harvest

ing with a binder. The acre cost of harvesting with a combine or binder (Tables 20 and 21) will be lower for large than for small acreages. The profitable minimum acreage for a combine will be set at a point below which the binder method will prove cheaper. The actual cost of the harvesting and threshing operations should be supplemented by a consideration of the probable effect of both methods on the labor program of the farm, the effect on following crops, the efficiency of each method in handling the crop, and the effect on the condition and value of the threshed crop.

In the Corn Belt an operator will find, according to the figures presented in Tables 19 and 20, that his harvesting cost will be less with a 10-foot combine than with an 8-foot binder and threshing with a stationary separator, if he has about 80 acres of grain. (Fig. 9.) Custom cutting of small grain in the Corn Belt in 1927 was done for about $2.75 an acre. Based upon costs in effect at that time, it would be cheaper for a farmer to hire his grain harvested with a combine

than to purchase a machine providing he had less than 130 acres of small grain. The rate charged for harvesting soybeans and clover amounted to approximately $3.20 an acre. Based upon the cost of harvesting these crops, it would be cheaper to hire the work done unless there were about 100 acres of both to be harvested with a combine. Costs of operation for combines larger or smaller than the 10-foot auxiliary motored-type would be greater or less and the profitable maximum acreage would vary accordingly.

The average of estimates of operators interviewed as to the least acreage of all crops for which they thought a combine would be profitable are shown in Table 22. These estimates ranged from 95 acres for the 8-foot power take-off outfit to 225 for the 12-foot auxiliary motored machines.

TABLE 22.—*Owners' estimates of minimum acreage of several crops for which a combine is profitable*

Type of combine	Width of cut	Number estimating	Average minimum area
	Feet		*Acres*
Tractor drawn, with power take-off	8	5	95
	10	33	131
Tractor drawn, with auxiliary engine	9	8	160
	10	28	193
	12	13	225
Total or average		87	166

In making their estimates, farmers for the most part considered factors other than the first cost of combines and binders—rather the saving in labor, freedom from hired harvest hands, elimination of a long threshing season, and the greater saving in grain.

The maximum acreage of small grain which an 8-foot binder will handle safely in a season is approximately 200 acres, or 13 days' work at the rate of 16 acres a day. A 10-foot combine cutting an average of 20 to 25 acres a day would cover about 350 acres in 15 working days. In harvesting soybeans the 10-foot combines averaged about 2 acres an hour for a 6-hour day. Many operators harvest larger acreages than these in a season, but acreages much greater than these would not be safe to figure on because of seasonal differences. In the Corn Belt in 1927 the maximum acreage cut with a 10-foot combine was 675 acres. The acreage included wheat, oats, buckwheat, and millet, and would have been still larger had clover and soybeans been harvested.

THE HARVEST SEASON

July and August are the months for the harvest of small grains in Illinois and Indiana, and the soybean harvest usually begins around October 10. Between these two periods there is ample time for the completion of the small-grain harvest in the event of unusual delay. The soybean harvest, however, is handicapped by the rush of other fall work, shorter working days, and often by unfavorable weather. Frequently soybean harvest extends well into the winter months.

RAINFALL

One of the chief factors determining the acreage a machine can safely harvest during a given period is the weather. The average annual rainfall and the summer monthly rainfall at Urbana, Ill., and at Indianapolis, Ind., as compared with that of other sections where combines are used are shown in Table 23. This table covers a period of 18 to 57 years for the different stations and although not a true measure for any one particular year, should be indicative in a general way.

TABLE 23.—*Average annual and monthly precipitation at 14 stations in wheat-growing sections of the Great Plains and in humid eastern sections of the United States*

Station	Length of record	Precipitation						
		Annual	June	July	August	September	October	November
	Years	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Urbana, Ill	24	34.25	3.22	3.38	3.22	3.03	2.28	2.13
Indianapolis, Ind	55	41.49	4.25	4.11	3.32	3.04	2.78	3.52
Canadian, Tex	18	23.10	3.70	2.26	2.56	2.46	2.08	1.29
Alva, Okla	27	28.28	3.69	2.76	4.05	3.11	2.38	1.49
Minneapolis, Kans	36	25.41	4.00	3.06	3.16	2.70	2.02	.98
Madrid, Nebr	33	18.31	3.44	2.44	2.40	1.20	1.09	.45
Lewistown, Mont	29	19.97	3.59	2.34	1.49	1.76	1.32	.74
Amenia, N. Dak	31	20.11	3.85	2.98	2.69	1.93	1.29	.64
Watertown, S. Dak	33	21.96	3.87	3.05	3.00	1.99	1.36	.75
St. Paul, Minn	56	28.63	4.40	3.38	3.43	3.44	2.33	1.30
Des Moines, Iowa	48	32.07	4.51	3.58	3.50	3.53	2.55	1.47
Kansas City, Mo	38	37.52	4.69	4.77	4.76	3.77	2.29	1.85
Columbus, Ohio	48	37.02	3.49	3.65	3.19	2.51	2.32	3.11
Harrisburg, Pa	57	37.30	3.56	3.86	4.22	2.85	3.03	2.35

The precipitation in July or August at Urbana and Indianapolis is greater than in November, but the delays incident to harvest may be less serious because of the more rapid drying. A heavy summer shower, if followed by bright sunshine and gentle breezes, delays harvest but a comparatively short time. The soil is soon dry enough to furnish traction to machinery, and the grain dries out quickly, especially if it is standing. In the fall, however, the same amount of rain may delay harvest several days because of slower drying conditions. Often the standing crop, although dried out sufficiently, can not be cut because of the soggy condition of the ground. Likewise the shocked beans may be so saturated after a heavy rain that it may be necessary to spread the shocks out to expedite drying.

The precipitation shown for Indianapolis, Ind., is 4.11 inches in July, which is higher than that for any other station reporting except Kansas City, Mo. This would place harvesting at a disadvantage in this section where the monthly rainfall is a true cause of delay. It is, however, the frequency rather than amount of rain that holds up threshing operations. From this standpoint, the stations in Illinois and Indiana show that, over a period of 14 years, there was an average of but 3.8 days and 4.8 days, respectively, on which 0.1 inch or more of rain occurred during July. Assuming the suspension of threshing operations on these days, there remains, on the average during the month, 27 days in Illinois, and 26 days in Indiana on which the harvest may be carried on. (Table 24.) In 1927, however, there were seven days at both stations on which rains occurred during July.

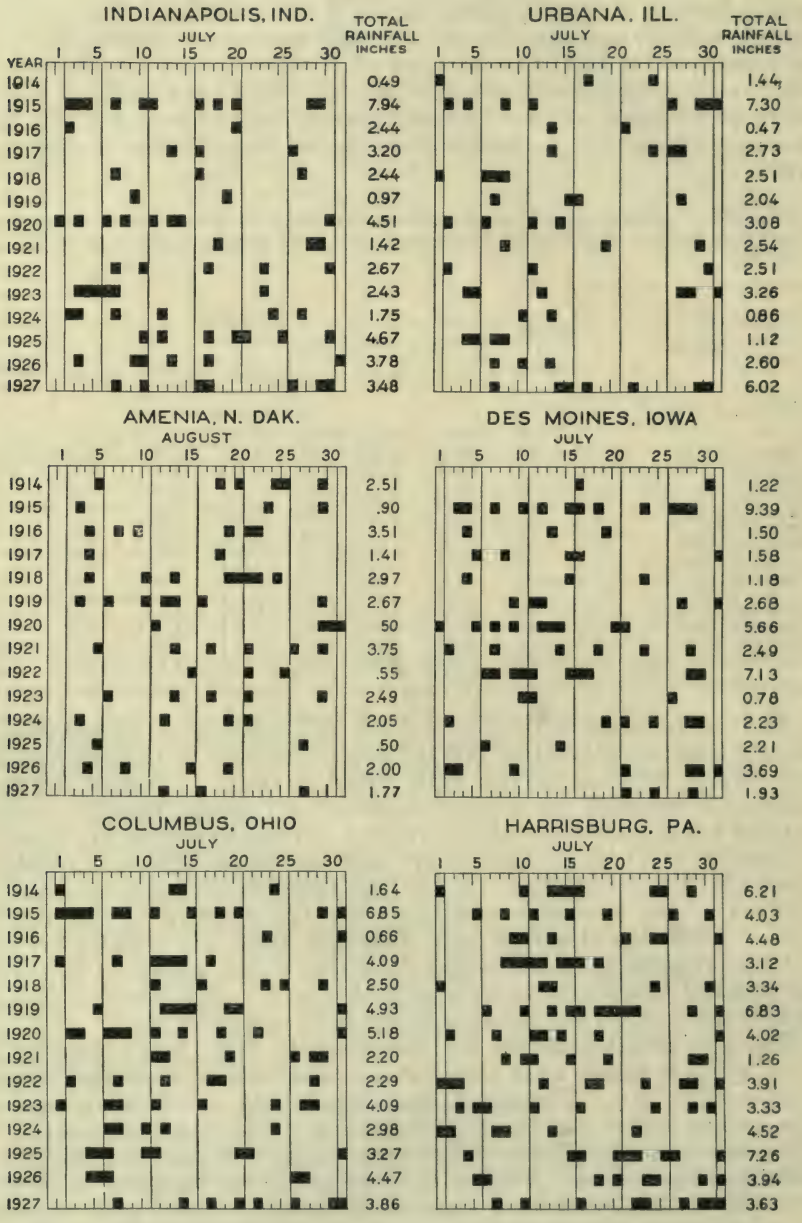

FIGURE 10.—DAYS ON WHICH RAINS OF 0.1 INCH OR MORE OCCURRED DURING THE HARVEST MONTHS FOR SMALL GRAIN AT 6 STATIONS DURING 14 YEARS, 1914 TO 1927, INCLUSIVE

Weather during the harvest season is one of the chief factors to be considered in determining the acreage of small grain which a combine can safely handle.

TABLE 24.—*Duration of small-grain harvest season and average number and percentage of rainy days at 10 stations in the Great Plains and humid eastern sections of the United States during the 14 years, 1914 to 1927, inclusive*

Station	Duration of the usual harvest season, inclusive, dates	Harvest season (days)	Days having 0.1 inch or more of rainfall	
			Number	Percentage of harvest season
Urbana, Ill.	July 1 to July 31	31	3.8	12.3
Indianapolis, Ind.	do	31	4.8	15.5
Alva, Okla.	June 15 to July 15	31	5.8	18.7
Minneapolis, Kans.	June 20 to July 31	42	7.3	17.4
Madrid, Nebr.	July 15 to Aug. 15	32	5.6	17.5
Amenia, N. Dak.	Aug. 1 to Aug. 31	31	5.0	16.1
Lewistown, Mont.	Aug. 1 to Sept. 30	61	7.2	11.8
Des Moines, Iowa	July 1 to July 31	31	5.6	18.1
Columbus, Ohio	do	31	6.7	21.6
Harrisburg, Pa.	do	31	8.0	25.8

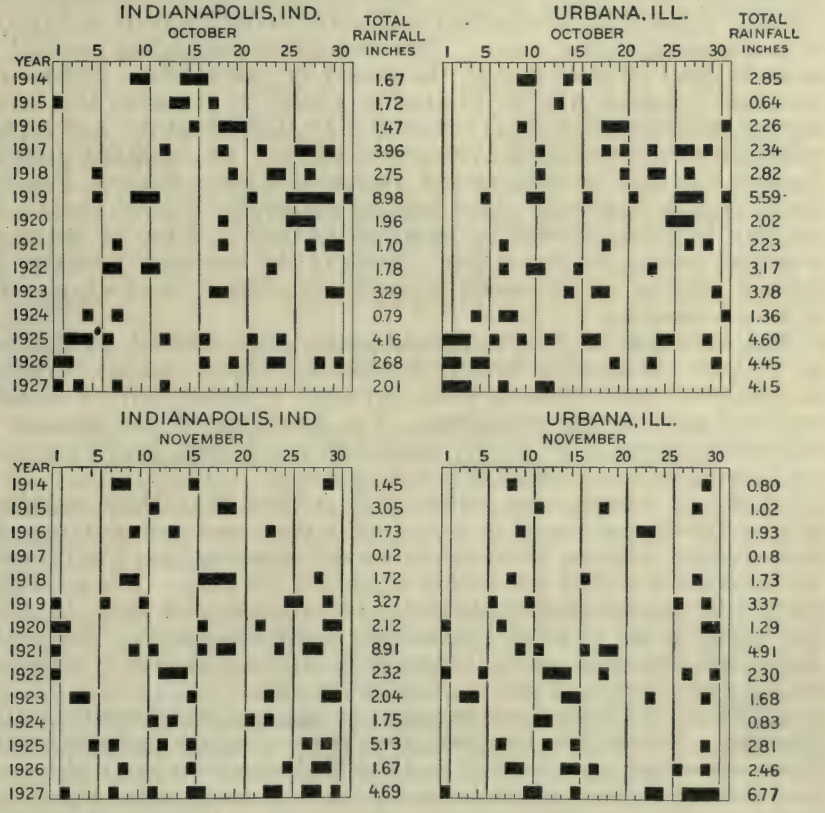

FIGURE 11.—DAYS ON WHICH RAINS OF 0.1 INCH OR MORE OCCURRED DURING THE HARVEST MONTHS FOR SOYBEANS AT URBANA, ILL., AND INDIANAPOLIS, IND., DURING 14 YEARS, 1914 TO 1927, INCLUSIVE

Weather is an important factor in the harvesting of soybeans but it is not so important as in small grains because of the longer season in which the soybean crop can be harvested.

Figure 10 shows graphically the occurrence of rain during the summer harvest period for six reporting stations, and Figure 11 is a similar chart for the two stations, Urbana and Indianapolis, for the months of October and November, the harvest period for soybeans in Illinois and Indiana. No hail losses were reported in 1927. Serious hail injury seldom occurs in Illinois and Indiana.

WEATHER CONDITIONS

Most of the farmers reported good weather on the days on which harvesting was done, but a considerable number reported some medium or bad weather during combine harvest of small grains and soybeans. The weather was more favorable during the harvesting of small grains and soybeans with the binder, and of clover with the combine than was the case in combining small grains and soybeans.

QUALITY AND CONDITION OF GRAIN

When grain that is too damp is put into bins it heats or molds and is not in satisfactory market condition. Combine operators are inclined to begin harvesting before the crop is fully mature and before it is dry enough after rains. This premature harvesting resulted in some heating of grain during the period of this study. Eighty-one combine operators had no heating in wheat; 12 reported that some heated, although 6 of these reported only slight heating, and replies were not obtained from the remaining 8 men. In combined oats, 64 farmers reported no heating and 19 reported some heating, 2 of the latter stating that only slight heating occurred. Barley apparently was not so much affected by moisture, as only 5 of the 34 operators reported heating in that grain. None of the combine operators reported heating in the seeds of soybeans, clover, buckwheat, rye, millet, or timothy.

The condition of their combined grain was described by farmers in Illinois. Thirty-one farmers estimated a higher moisture content in combined grain than in grain cut with a binder, but 15 farmers reported that it was no higher. The estimates of the increase in moisture content were mostly from 1 to 5 per cent, but 2 reported an increase in the moisture of 8 to 10 per cent.

Of the 52 farmers who reported, 37 replied that their combined grain suffered no discount or reduction in price on account of its moisture content, whereas 15 reported discounts ranging from 1 to 12 cents and averaging 5 cents per bushel on part of the crop. The price of a part of the combined grain thus was cut an average of about 1½ cents per bushel on the 52 farms because of excessive moisture. Those who harvested the grain when in proper condition and free from green weeds and clover suffered no discount in price.

Only 3 of 41 Illinois farmers reporting had any grain rejected at the elevator. One of these disposed of the rejected wheat later after it had dried somewhat, another had some spoiled wheat on hand, the third had some volunteer wheat containing an excess of about 5 per cent moisture which could not be handled by the elevator. Only 3 of the 69 Illinois farmers interviewed reported that grain-drying equipment was available at their local elevators.

Moisture determinations were made on 87 samples of wheat and 71 samples of soybeans from combines, and 18 samples of wheat and 17 samples of soybeans threshed with separators in Illinois and Indi-

ana. In addition, 1 sample each of rye and barley and 14 samples of oats cut with the combine were taken for moisture determinations. These samples were taken throughout the day under varying weather and crop conditions. On some farms several samples were taken during the day in order to determine the diurnal variation in moisture content. The weather in Indiana at the time many of these periodic samples were taken was damp or rainy. Average moisture contents for wheat, oats, and soybeans threshed with combines and separators are shown in Table 25. The averages shown are averages by farms instead of all individual samples in order to get the average of all lots of combined wheat. The extremes shown are for individual samples. All samples obtained are included in these averages except one from Indiana containing 22.8 per cent moisture, which was obtained while a farmer was trying out his combine in immature wheat 6 days before his regular harvest began.

TABLE 25.—*Moisture content of wheat and soybeans threshed with combines and separators in Indiana and Illinois and the moisture content of oats threshed with combines*

State and method	Wheat					Soybeans					Oats				
	Sample	Farms	Moisture content			Sample	Farms	Moisture content			Sample	Farms	Moisture content		
			Average	Minimum	Maximum			Average	Minimum	Maximum			Average	Minimum	Maximum
Illinois:	*No.*	*No.*	*P. ct.*	*P. ct.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*P. ct.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*P. ct.*	*P. ct.*
Combine	48	29	14.4	11.3	20.8	38	12	11.7	9.2	13.9	4	2	13.8	13.1	14.5
Separator	11	8	14.4	12.8	16.3	2	1	14.1	13.9	14.2	-----	-----	-----	-----	-----
Indiana:															
Combine	39	12	15.2	12.0	19.4	33	10	13.6	10.2	19.8	10	4	15.9	14.0	20.0
Separator	7	4	14.8	13.0	15.4	15	6	15.3	11.6	26.5	-----	-----	-----	-----	-----

The damp weather and many green weeds interfered with oat harvest in Indiana and caused the rather high moisture content.

The above results show that the difference in moisture content between combined and shock-threshed wheat was very small on the average and that the slightly higher moisture content was due to occasional combining when the crop was not in condition for harvesting.

The moisture content of soybeans threshed with combines was lower than that of those threshed with separators in both Indiana and Illinois. The average moisture content of soybeans harvested with the combine on 22 farms in both States was 12.6 per cent. The average moisture content of soybeans harvested by other methods and threshed with separators was 15.1 per cent or 2.5 per cent higher than the combined soybeans. This difference is due to better drying of the standing crop as compared with that left in the shock or bunch.

The relation of the time of day of harvesting and the moisture content of combined wheat was much less marked than has been indicated in other sections. Samples of combined wheat were taken at intervals during the day in some cases during two or three consecutive days in four fields in Indiana and two in Illinois. The drying of the wheat during nine different days varied from 0.02 per cent

less moisture content per hour to 0.43 per cent. The average hourly decrease in moisture content during nine days in six wheat fields was 0.19 per cent.

A frequency distribution of the moisture content and time of day of combining of 85 samples of wheat in Indiana and Illinois is shown by a dot chart in Figure 12. The average decrease in moisture content was determined by least square methods and is shown by the regression line in the chart. This line shows that on the average the moisture content of combined wheat was reduced 0.25 per cent per hour. On this basis, if wheat contained 16 per cent moisture by 8 a. m., it might be expected under the average conditions to contain 2.5 per cent less or 13.5 per cent moisture at 6 p. m. During some days drying was nearly twice this rapid but on still, damp, cloudy days there was little or no decrease in moisture content. A similar study

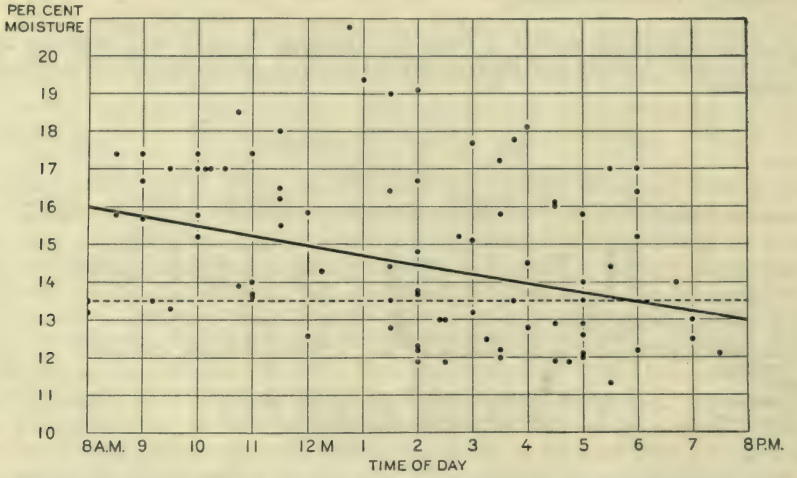

FIGURE 12.—INFLUENCE OF TIME OF DAY ON MOISTURE CONTENT IN COMBINED WHEAT, ILLINOIS AND INDIANA, 1927

On the average the moisture content of combined wheat is reduced 0.25 per cent per hour. Wheat that contains 16 per cent moisture at 8 a. m., under average conditions would contain 13.5 per cent moisture at 6 p. m.

of combined wheat in South Dakota in 1927 showed an average decrease in the moisture content of about 0.3 per cent per hour.

The distribution of the dots in Figure 12 shows that a greater proportion of the samples of wheat combined in the afternoon contained less than 14 per cent moisture than was true of samples of wheat combined in the forenoon. It shows that combined wheat in the Corn Belt may contain less than 14 per cent moisture when harvested as early as 8 a. m. and that many samples of wheat harvested after noon contained 15 to 20 per cent of moisture. The chart further shows that a certain set hour of the day is not a safe time for starting combining each day.

Maturity of the crop, presence of green weeds, occurrence of rain, dew, humidity, wind, and the prevailing temperatures, are the factors that determine the condition of the grain at harvest time.

An examination of 12 samples of soybeans threshed with a combine in Illinois showed an average of 89.8 per cent of clean, whole seed, 9.4 per cent of split seed, 0.2 per cent of damaged seed and 0.6 per

cent of foreign material. One sample of soybeans threshed with a separator contained 91.4 per cent clean, whole seed, 7.6 per cent split seed, 0.1 per cent of damaged seed, and 0.9 per cent of foreign material. These analyses are similar. The percentage of split seed in the combined samples varied widely, ranging from 0.2 to 22.8 per cent in different samples. This variation resulted from differences in machine adjustment and operation and in the toughness of the beans.

GRAIN HANDLING AND STORING

There is a widespread belief that all marketable combined grain is hauled off and sold at once, thus flooding the market, taxing the shipping and storage facilities, and lowering the price. It is generally believed that farmers are afraid to store combined grain. It is true that in areas where large numbers of combines have come into use, as in the Great Plains, wheat is marketed in a much shorter period than was usual. This is not due to a change in practice after the grain is threshed, but merely to the method of harvesting and threshing. With combines, more grain is ready in a shorter period than when binders and threshing machines are used, for it is sometimes necessary to wait long periods after harvesting before the threshing machine reaches the farm.

Farmers in the Great Plains, as a rule, have never held grain on the farm, as few have storage facilities except for their feed and seed requirements. The combine has not caused these men to change their marketing practices but has merely speeded up marketing.

If the combine were responsible for a general change in handling and storing grain, such change would be apparent in areas like the Corn Belt in which farm-storage facilities are usually ample to handle the year's crop. Data gathered from the interviewed combine and binder operators on grain disposal indicate that the former have not changed their practices, but are continuing to handle and store grain in about the same manner as are binder operators.

In an area in which combines are relatively new it is logical to suppose that much of the combined grain would be in poorer condition for farm storage than would grain handled in the usual way. Differences in the condition of combined and bound-and-threshed grain, therefore, would be reflected by the method of storing. On most Corn Belt farms storage facilities are sufficient to hold the bulk of the crop if desired. As a usual thing, however, certain quantities of the cash-grain crops are marketed to meet expenses that come due after the harvest season, and the remainder, except that needed for seed, is marketed at a later date.

In older combining sections where surveys have been made, it has been found that many farmers store only that part of their cash crop which is harvested during dry weather after the crop is fully ripe. The remainder of the crop, comprising that harvested early in the season before the grain is dry enough to combine and any that is cut too soon after showers is marketed immediately. When grain is allowed to stand so that it will be in better storage condition, rain may cause a greater loss than would have occurred had the crop been combined a little sooner. Weather conditions at harvest time may occasionally be contrary to conditions for best storage, consequently operators have to use considerable care in handling their grain throughout the season.

Moisture is the prime factor in determining the keeping quality of grain. However, grain that is stored at a high temperature is more likely to go out of condition than is grain that has the same moisture content and is stored at a lower temperature. The physical condition of the grain, the humidity, the air temperature, and the nature and quantity of foreign material also affect the keeping quality of the grain. Such observations as have been made indicate that under normal conditions the storage risk is considered to be reduced to a safe point when the moisture content of the grain is not over 13.5 per cent.

Tough grain that is stored during hot summer weather is more likely to go out of condition than is similar grain that is stored in cooler weather. The temperature of grain threshed on a very hot day and left standing in either a wagon or grain tank on a combine, exposed to the direct rays of the sun, will rise 5° or 10° above the temperature of the surrounding air. If such wheat is stored in a bin or put into a railroad car it probably will not keep as well as if it had remained at the air temperature.

Information on grain disposal obtained from the combine and binder operators interviewed, indicates that the use of a combine does not materially affect the marketing practice of the men who operated these machines.

Table 26 shows the bushels of different kinds of grain hauled from combines or stationary separators to the elevator or farm bin.

TABLE 26.—*Quantity of crops hauled to elevator or bin*

Crop	Total harvested	Hauled to bin	Hauled to elevator	
	Bushels	*Bushels*	*Bushels*	*Per cent*
HARVESTED WITH COMBINE				
Wheat	172,411	37,930	134,481	78
Oats	158,859	112,790	46,069	29
Barley	40,667	26,950	13,717	34
Soybeans	92,621	55,573	37,048	40
Clover seed	3,040	3,040	----------	0
HARVESTED WITH BINDER				
Wheat	34,255	8,251	26,004	76
Oats	47,495	37,225	10,270	22
Barley	715	715	----------	0
Soybeans	597	597	----------	0
Clover seed	60	60	----------	0

The quantity of wheat from combines going to the elevator amounted to 78 per cent of the total bushels harvested and that from stationary separators to 76 per cent. The remainder was kept on the farm for future sale and for seed. For wheat this would indicate that there was no difference in the condition of the crop from the storage standpoint at the time it was threshed. Of the oats, 29 per cent of the combined crop and 22 per cent of that from threshing machines went directly to market. On the farms with combines 34 percent of the barley was hauled to the elevator at once, whereas on the farms with binders it was all kept at home. With soybeans, 40 per cent of the combined crop was marketed at once whereas the binder operators kept all their beans. All the clover harvested was kept and marketed later.

Reference to Table 1 shows that the farms, with combines had 10 acres more of oats than did those on which binders were used, twelve times as many acres of barley, nearly four times as many of soybeans, and about an equal acreage of clover. The larger acreages of the feed crops, oats and barley, in the combine farms returned a total yield in excess of feed requirements; the excess was sold without holding. The difference in the handling of soybeans was also due to the difference in the total yield. No clover seed was sold at the time of threshing as it was felt that a better price could be obtained later. It is evident that, in 1927 at least, Corn Belt farmers felt that combined grain was in as good storage condition as was the grain from threshing machines.

COOPERATIVE OWNERSHIP

The first cost of a combine is a factor that a farmer must consider carefully before making a decision whether to buy one or to continue harvesting with a binder. If he has a comparatively small acreage of grain to harvest, the ownership of a combine by an individual farmer may not be warranted because of the cost of the outfit even though it enables him to complete his harvest in a shorter period, with less labor, and less expense than when he uses a binder and stationary separator.

Under such conditions the joint ownership of a combine is often practicable. When satisfactory arrangements can be made such ownership is to be recommended. If such ownership is not practicable and the individual farmer does not feel that he can afford to own a machine, there is another alternative and that is to hire his crop combined.

Of the 107 combine owners interviewed, 103 indicated whether their machines were owned outright or cooperatively. Of these men, 16 owned the machine jointly with a neighbor, and all felt that their arrangements were satisfactory.

The principal reasons for joint ownership are that it reduces the first cost of the combine to each partner and does away with hiring a man to operate the tractor or combine, as the owners can exchange work.

The best policy to follow when the machine is owned cooperatively is to have the man who runs the tractor and the man who operates the combine continue throughout the season in the same capacity. Changing off when harvesting different crops or on the farm of each owner will not result in efficient operation. There should be a distinct understanding as to how repairs are to be paid for. The most satisfactory arrangement is to prorate the cost to each owner on the basis of the acreage harvested by each. If each partner buys repairs there may be a tendency to neglect the replacement of worn-out parts when needed. There should also be a distinct understanding before the machine is purchased as to the order in which each man's job is to be handled. Failure to have a complete understanding beforehand covering all important points may make cooperative ownership unsatisfactory.

CUSTOM WORK

In communities where harvesting with combines is relatively new, the possibilities of doing custom work are often almost unlimited. Nearly every owner has done some custom work for neighbors or has had the opportunity of doing it.

Some operators have earned sums, from combining for neighbors, sufficient to pay a considerable part of the first cost of their outfits in one or two years. Others have received enough to cover the yearly expense of harvesting their own crops. Prospective combine owners should not, however, place too much dependence upon custom work as a means of paying in part for the machine, or as a source of income each year. Nor will a farmer always be justified in purchasing a combine when he has only a small acreage of his own grain to harvest with the idea that the custom work will make it a profitable investment. An increase in the number of combines in any community will result in competition among the owners, there may be less work for each owner, and the rates for cutting may be so reduced that profits may be extremely small.

Any profits to be made from custom harvesting with a combine depends upon the amount received per acre. Previous studies show that rates per acre, in sections where combines have been used for a number of years, are lower than in sections where the machines have been used only a short time, and that rates are more standardized in the older than in the newer sections. In the Great Plains the general rates were about $3 per acre. In the Corn Belt the average charges made for harvesting different crops by men who did custom work ranged from $2.90 to $3.50 an acre. Based upon costs of operating a combine, as given in Table 19, a farmer could hire his harvesting done with a 10-foot combine more profitably than if he purchased a machine unless he had at least 100 to 125 acres to harvest. Individual straight cash rates varied from $2 to over $6 per acre. Some operators added the cost of fuel and oil to the rate charged per acre, others charged on a straight bushel basis which made a total charge as low as 95 cents an acre in some instances, and finally there were those who charged a flat rate per acre plus a charge per bushel. Other miscellaneous rates were charged, but those mentioned were the ones most commonly used. In every community operators at first have difficulty in establishing a charge per acre that will return a fair profit to them and still make it desirable for neighboring farmers to hire their crops combined. In the sections where machines have been in operation for as many as eight years, rates are well standardized. Men who do custom work have fixed upon a flat charge of $1 an acre plus the going rate per bushel for threshing. When crop yields are not below normal this rate has proven satisfactory to both parties of the agreement.

Farmers who hire their crops harvested with a combine early in the season so that their grain will be out of the way before it is damaged or before possible losses occur from shattering and lodging usually expect to pay a higher rate. Later, when more combines are available and there is competition among operators for harvesting jobs, the rates are lower.

The rates charged and the returns for harvesting different crops are shown in Table 27.

TABLE 27.—*Crops and acres harvested by combine owners who did custom work*

Crop	Type of combine	Width of cut	Combine used for custom work	Area, own crop	Area, custom cutting	Charges per acre for cutting	Total receipts	Total expenses [1]	Returns from—			
									Combine [2]		Combine and labor [3]	
									Total	Per acre	Total	Per acre
		Feet	*Number*	*Acres*	*Acres*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Wheat	Tractor drawn, with power take-off.	8	6	20	54	2.79	150	30	120	2.22	138	2.56
		10	12	49	50	2.84	143	25	118	2.36	135	2.70
	Tractor drawn, with auxiliary engine.	9	3	62	56	2.42	135	36	99	1.77	120	2.14
		10	11	68	67	3.00	202	41	161	2.40	185	2.76
		12	8	29	80	3.24	259	45	214	2.68	238	2.98
	All tractor drawn		40	49	62	2.96	183	35	148	2.39	168	2.71
Oats	Tractor drawn, with power take-off.	8	3	24	45	2.61	118	19	99	2.20	109	2.42
		10	9	22	45	3.02	135	21	114	2.53	129	2.87
	Tractor drawn, with auxiliary engine.	9	3	33	63	2.58	163	40	123	1.95	146	2.32
		10	8	42	63	2.89	183	40	143	2.27	166	2.63
		12	5	46	65	3.15	206	42	164	2.52	186	2.86
	All tractor drawn		28	33	56	2.91	163	32	131	2.34	149	2.66
Barley	Tractor drawn, with power take-off.	8	1	47	25	3.48	87	21	66	2.64	80	3.20
		10	2	------	48	4.21	204	23	181	3.77	200	4.17
	Tractor drawn, with auxiliary engine.	9	1	------	31	3.00	93	27	66	2.13	83	2.68
		10	2	10	25	3.65	90	12	78	3.12	84	3.36
		12	6	23	75	3.08	232	40	192	2.56	215	2.87
	All tractor drawn		12	17	55	3.31	181	30	151	2.75	169	3.07
Soybeans	Tractor drawn, with power take-off.	8	5	19	47	2.94	137	25	112	2.38	125	2.66
		10	15	54	90	3.24	292	46	246	2.73	277	3.08
	Tractor drawn, with auxiliary engine.	9	3	3	94	3.54	332	61	271	2.88	318	3.38
		10	12	34	92	3.78	350	57	293	3.18	326	3.54
		12	7	28	76	3.48	265	48	217	2.86	245	3.22
	All tractor drawn		42	36	84	3.45	289	48	241	2.87	270	3.21
Clover	Tractor drawn, with power take-off.	8	------	------	------	------	------	------	------	------	------	------
		10	3	5	20	2.82	56	17	39	1.95	54	2.70
	Tractor drawn, with auxiliary engine.	9	1	------	38	4.00	152	71	81	2.13	139	3.66
		10	5	7	50	3.03	153	42	111	2.22	139	2.78
		12	2	------	136	3.98	542	118	424	3.12	495	3.64
	All tractor drawn		11	5	57	3.48	197	52	145	2.54	180	3.16

[1] Expenses include charges for labor, fuel, oil, and grease. No other charges are included.
[2] Total return to combine is the profit for use of combine and tractor with cost of labor, fuel, and lubricants deducted, but with no charge for depreciation and repairs.
[3] Return to combine and labor is the profit for operating a combine and tractor with charges made for fuel and lubricants, but with no deduction for labor, depreciation, or repairs.

For each crop and with the machines doing custom work, the average acreage of custom cutting was considerably higher than the acreage of harvesting on the home farm. Rates other than a flat charge were converted in the tables into a straight dollars-and-cents charge. The average rate charged was below $3 an acre for oats and wheat; for soybeans, barley, and clover, the rate was approximately 50 cents higher. For each crop the returns per acre differ for each size of machine. Were it not for the differences in the rates charged per acre, these returns would be practically the same.

The lowest net return (exclusive of the fixed charges, depreciation, interest, and repairs) averaged $2.34 an acre for all machines on oats. The crop showing the highest net return was soybeans which averaged $2.87 an acre. If no charge is made for the operator's labor, the return on oats would amount to $2.66, and for soybeans $3.21, an acre.

Whether it will be profitable for an operator to do custom work on an extensive scale at these returns will depend upon the work which requires his attention at the same time upon his own farm. He may find it more profitable to prepare his land for next year's crop and let the machine stand idle, although he may be able to hire his own work done at a cheaper rate while he does the custom work.

SUMMARY

The first combine introduced into the Corn Belt was used in Illinois in 1924. Since that year the number has increased rapidly, and the machine has given general satisfaction in harvesting small grains and legumes.

Advantages of the combine are as follows: (1) It lowers the cost of harvesting and threshing; (2) it reduces the amount of labor required; (3) it shortens the harvest and threshing period; and (4) it furnishes a satisfactory means of harvesting the soybean crop.

The chief disadvantage of combine harvesting in the Corn Belt is the difficulty of obtaining the needed quantities of straw.

The most common type of combine used in the Corn Belt is the auxiliary-motored outfit with a cut of 9, 10, or 12 feet. The power-driven outfits in use have cuts of 8 and 10 feet.

Nearly 70 per cent of all the combines studied have a 10-foot cutter bar.

The binders in most general use have a cut of 8 feet, other binders with 6, 7, and 10 foot cuts are used.

The latest type of binder to come into use is the 10-foot power-driven outfit which obtains its operating power from the tractor that pulls it.

Tractors with a drawbar rating of 15 horsepower were used to pull about two-thirds of all the combines, and nearly one-third of them were pulled by tractors with a drawbar rating of 12 horsepower or less.

Seventy per cent of the binder operators used horses, and 30 per cent used tractors to pull their machines. The number of tractor-drawn binders were about equally distributed between 7, 8, and 10 foot sizes. Three-horse teams were used exclusively by the operators of 6-foot binders, and 4-horse teams by operators of 7 and 8 foot machines.

Of 101 combine operators who grew wheat, only 4 used a binder to harvest any part of the crop. Of 99 operators who grew oats, 83 used their combines exclusively to harvest the crop. Out of 85 men who grew soybeans, 68 used their combines. All but 2 of 36 combine owners who grew barley used their machines. Twenty-nine of the operators who grew clover of different varieties used their combines. Seventeen of twenty-four men growing miscellaneous crops harvested with a combine.

The average acreage of all crops harvested with combines of all sizes amounted to 263 acres per machine, of which 154 acres was harvested on the home farm and 109 acres was custom work. The average acreage harvested with machines of different sizes ranged from 170 acres for the 8-foot machines to 311 for the 12-foot outfits.

Binder operators used their machines to harvest an average of 98 acres of all crops per machine, of which 85 acres was harvested on the home farm and 13 acres was custom work. The average acreage

harvested per machine ranged from 50 for the 6-foot binder to 176 for the 10-foot tractor-drawn outfit.

On the average small-grain combining was done on 14 different days, of which time a total of 7.6 days were spent in harvesting. With binders, the time covered 17 days, of which 5.4 days were spent in harvesting.

The average rate of travel of combines in small grain and soybeans was 2.7 miles per hour and 1.8 in timothy and clovers. Tractor-drawn binders averaged 3.2 miles per hour and horse-drawn binders were calculated at about 2.3 miles.

The average length of working day for combines in small grain was 9 hours and in soybeans 6.1 hours. For binders in small grain the working day averaged 9.5 hours and in soybeans 6.7 hours.

The average acreage of small grain harvested daily varied from 13 acres for the 8-foot combines to 24 acres for the 12-foot. In soybeans the acreage for the same sized outfits varied from about 7 to 14 acres respectively. For binders the acreage of small grain harvested daily varied from 14 acres for the 6-foot machines to 34 acres for the 10-foot machines.

The average acreage of small grain cut per hour per foot of width of cut, for combines, was about 0.21 acre; the corresponding acreage for soybeans and clovers were 0.19 and 0.14 acre respectively. In small grain, horse-drawn binders cut 0.23 acre per hour per foot of width and tractor-drawn binders cut 0.31 acre.

Lodging was the cause of some difficulty in harvesting, but of 89 combine operators who reported, 67 considered the combine better than the binder in lodged grain.

Weeds interfered with combining on some farms as they caused the combine to pull with more difficulty. They also increased the moisture content in the grain.

Shattering of grain due to long standing in the field was scarcely apparent, and various weather damage was not general.

Practically all the combines were considered reliable by their owners as only 3.2 hours, on the average, was lost on account of breakdowns by a machine during the harvest season. The average time lost by binder operators amounted to 1.9 hours each.

Because of a difference in the method of determining losses and a difference in the crop at harvest time, harvesting wheat in Illinois with combines showed a 6.6 per cent loss and in Indiana a 3 per cent loss. With binders the loss in Illinois was 3.6 per cent and in Indiana 2.8 per cent.

Threshing losses in wheat for combines showed a loss of 2.6 per cent in Illinois and 0.5 per cent in Indiana. With stationary separators the losses were 1.5 per cent for Illinois and 0.8 per cent for Indiana.

The number of men used on the combines averaged less than two per machine. For the binders the average was nearly three and one-half men per machine including shockers.

The average amount of man labor for harvesting wheat with a combine amounted to 0.78 man-hour per acre and 3.6 man-hours with a binder and stationary separator.

The fuel used in the auxilliary motor and tractor when harvesting small grain averaged 1.5 gallons per acre, oil 0.06 gallon, and grease 0.09 pound.

Based on other studies, repairs on combines were estimated at 10 cents an acre. Repairs on binders amounted to about 3 cents an acre for the year.

Combine owners estimated a $12 yearly charge for shelter of their machines and binder operators estimated $5.

The average charge for depreciation on all combines amounted to 53 cents per acre and on binders to 13 cents.

Interest is a fixed charge, and the per-acre charge is less for large than for small acreages.

If as many as 80 acres of crops are to be harvested, a 10-foot combine may prove more economical than an 8-foot binder.

The variable costs per acre based upon charges made for harvesting wheat by either method, are $1.07 for a 10-foot combine and $3.44 for an 8-foot binder.

Estimates for the minimum profitable acreage for combines range from 95 for the 8-foot size to 225 acres for the 12-foot.

The maximum acreage cut with a 10-foot combine was 675 acres, exclusive of soybeans.

Average charges made for harvesting different crops by men who did custom work ranged from about $2.90 to $3.50 per acre.

The cooperative ownership of a combine was satisfactory to all the men who owned them jointly.

Little trouble was experienced by combine operators from heating of harvested grain.

The moisture content in soybeans was lower in those harvested with a combine than in those harvested in other ways and threshed with a separator.

The use of a combine has not materially affected the marketing practices of the men who operated these machines.

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TECHNICAL BULLETIN No. 245 JUNE, 1931

ARSENICAL AND OTHER FRUIT INJURIES OF APPLES RESULTING FROM WASHING OPERATIONS

BY

D. F. FISHER
Principal Horticulturist

AND

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Junior Pathologist
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Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page		Page
Introduction	1	Injury at the core	9
Arsenical injury	2	Heat injury	9
Occurrence in the orchard	2	Influence of washing on storage rots	10
Occurrence on stored apples	3	Conclusion	11
Methods of prevention	7	Summary	11
Hydrochloric-acid injury	8	Literature cited	12
Injury from alkaline solvents	9		

INTRODUCTION

The susceptibility of apples to arsenical-spray injury has been recognized for many years. Its cause and prevention have furnished the basis for a long series of investigations, most of which, however, have dealt primarily with foliage injury.

The experimental work previously reported has established the fact that arsenical-spray injury is due primarily either to the original content of water-soluble arsenic, to interactions in the spray mixture which liberate water-soluble arsenic, or to reactions of leaf extractives with the spray material.

The investigation now reported is concerned particularly with arsenical injury of apples at harvest time or during storage and was conducted at the United States Fruit Disease Field Laboratory at Wenatchee, Wash.

Since 1927, when chemical solvents were first employed in commercial fruit-washing operations in the Pacific Northwest, injury at the calyx has been found frequently on washed apples. It was first described as "calyx scald," because it appeared most frequently in the calyx region, although it occasionally occurred in the stem cavity as well (*2*).[1] The injury shows as a black or brown ring surrounding the calyx, or less frequently as dark patches of dead skin

[1] Italic numbers in parentheses refer to Literature Cited, p. 12.

on the sides of the calyx cavity. At first the injury is very superficial, but in advanced stages it becomes depressed and extends one-eighth of an inch or more into the flesh, which becomes brown and dry. (Pl. 1.)

The particular type of injury concerned in the present discussion first came to general notice in 1927, on apples that had been washed in dilute hydrochloric acid. This association of the injury with acid washing led to a popular belief that it was caused by hydrochloric acid and possibly resulted from the rinse water having become too acid. However, elimination of traces of acid in the rinse water and even the use of sodium bicarbonate to neutralize acidified rinse solutions did not entirely prevent the injury.

Calyx scald was frequently followed by rot invasion. (Pl. 2, A.) The fungi most frequently encountered in these calyx rots were *Penicillium expansum*, *Macrosporium* sp., and *Cladosporium* sp. With certain methods of washing and types of equipment that were discarded as soon as their objectionable features were discovered, the losses sometimes reached 60 per cent within three or four weeks after washing (*3*). Confidence in the commercial value of washed apples was almost destroyed, and fruit growers and shippers of the Northwest experienced a period of extreme anxiety verging almost on panic. The fruit industry faced the necessity of removing spray residue in order to market the apple crop, and where this could only be accomplished by washing, it appeared that the keeping quality of the apples might be destroyed.

ARSENICAL INJURY

OCCURRENCE IN THE ORCHARD

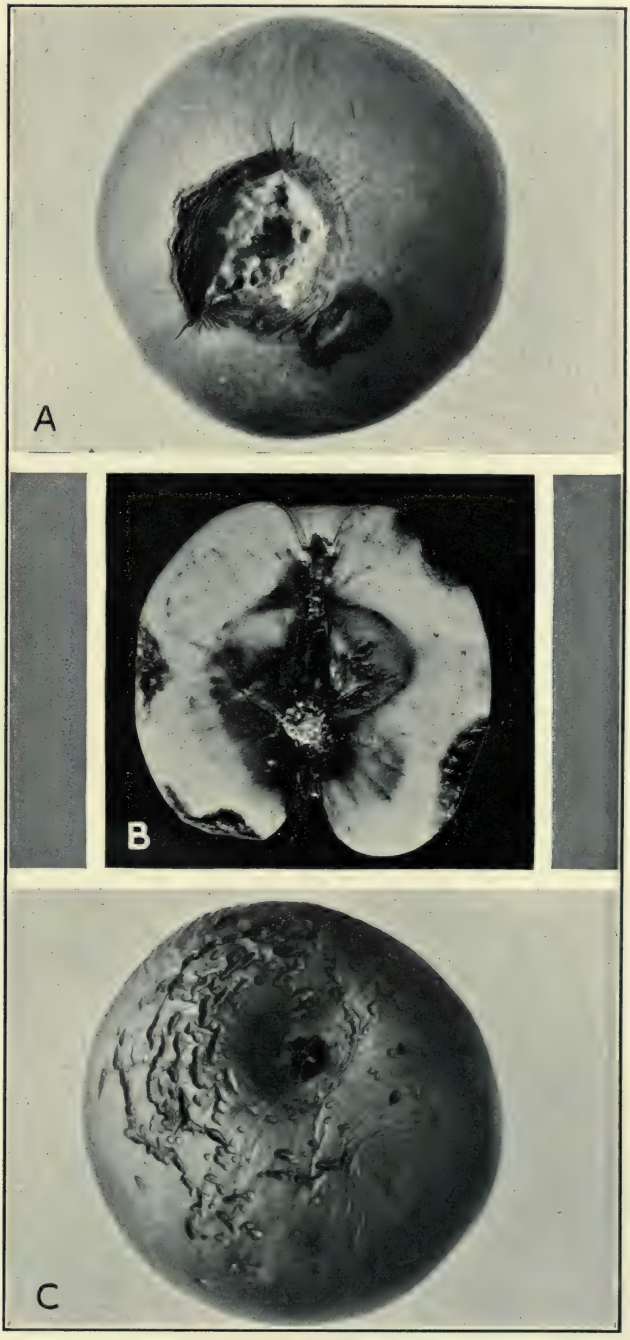
For many years arsenicals of various kinds have been used for spraying plants. One of the first experiments with soluble arsenic on apples to be reported was that of Gillette (*4*), who found that arsenious acid in dilutions as weak as 1 to 1,200 caused severe injury to the foliage. In later work he reported that the injury could be prevented entirely by the addition of milk of lime (*5*). Since then the use of lime with arsenical sprays has become an established procedure wherever tender foliage is sprayed or where there is danger of encountering much soluble arsenic in the spray mixture. Two types of lead arsenate are used for insecticidal purposes—basic lead arsenate and lead hydrogen arsenate, commonly known as acid lead arsenate. At the present time lead hydrogen arsenate has almost completely supplanted the earlier use of Paris green and other arsenicals for spraying apple trees, on account of its low content of water-soluble arsenic. Numerous investigations on the injurious effects of arsenical sprays have been conducted, and agreement has been reached in attributing the damage to soluble arsenic. In recognition of the danger from soluble arsenic, regulatory measures enforced by State and Federal authorities provide that lead arsenate offered for sale shall not contain more than 0.75 per cent of water-soluble arsenic pentoxide, As_2O_5 (on the basis of the paste form of lead arsenate, which contains 50 per cent water).

Although protected by law against the danger of purchasing lead arsenate that contains injurious quantities of soluble arsenic, the

Litho. A. Hoen & Co., Inc.

A.—Injury from soluble arsenic around calyx of a Grimes Golden apple

B.—Section of a Jonathan apple showing injury from soluble arsenic to tissue at both calyx and stem end



A, Fungus rot following arsenical injury at calyx of a Jonathan apple; B, core rot of Jonathan apple, resulting from penetration of washing solution contaminated with fungus spores through open calyx tube; C, heat injury to Jonathan apple caused by exposure for three minutes in hydrochloric-acid washing solution heated to 110° F.

fruit grower is still confronted with the injurious effects of arsenic rendered soluble after the spray is applied. Headden (*7*), Haywood and McDonnell (*6*), and others have shown that in many cases soluble arsenic is formed by dissolved salts in the water used. Volck (*11*) found that lead hydrogen arsenate is unstable in the presence of meteoric water, forming basic lead arsenate and arsenic acid. This was confirmed by McDonnell and Graham (*8*), who studied the decomposition of dilead arsenate in pure water. Mogendorff (*9*) found that the decomposition of lead arsenate, with formation of soluble arsenic, is favored by an alkaline medium either formed from salts present in the spraying water or produced by the leaves. He found, moreover, that injury is caused only after the arsenic has accumulated in the leaf tissues. All these investigations have been concerned with foliage injury.

The type of arsenical injury discussed in this bulletin is known to occur in eastern districts, but apparently it has affected the market value of the fruit but little, if at all. Although this fruit injury was observed by the writers in the Wenatchee Valley from time to time long before apple washing became part of the ordinary packing procedure, it occurred so rarely in the orchard as to escape general attention. However, with the rise of fruit-cleaning problems in the last few years, it has assumed importance on packed apples in storage (*2*, *3*).

During rainy fall weather this injury has been observed on heavily sprayed apples before harvest, but more commonly it has been found on picked apples that were allowed to stand unprotected through rainy weather. Its greater prevalence in the latter case may doubtless be explained by the fact that apples in boxes are slower to dry than when they are on the tree, and the quantity of soluble arsenic increases with the length of time the apples remain wet.

In the irrigated apple-growing districts of the Pacific Northwest it is often necessary to apply six or seven sprays of lead arsenate during the season in order to control the codling moth. The last spray is sometimes applied not more than a month before harvest. The growing season is practically rainless, and spray residue therefore is not markedly diminished by natural climatic factors as is the case in the more humid districts. On the contrary, there is a continual increase in the amount of lead arsenate on the fruit as a result of spray applied, so that the maximum load is found near harvest time. The apples of this region therefore often carry heavy loads of arsenical spray residue when picked from the tree, particularly in the case of varieties like the Winter Banana, Grimes Golden, and Jonathan, which are picked early in the season. Arsenical residues, calculated as As_2O_3, often reach 0.07 or more grains per pound of fruit. Foliage injury is usually negligible under northwestern conditions, and the fruit injury has seldom been severe enough to cause any serious loss, although occasionally 10 per cent or more of a crop has been culled on this account.

OCCURRENCE ON STORED APPLES

Before the removal of spray residue was attempted, injury of the arsenical type had been observed also on commercial lots of apples that were stored wet in poorly ventilated rooms. During the harvest

rush apples are sometimes stored loose in orchard lug boxes before being packed. To prevent wilting, the stacked apples are sometimes kept wet for long periods by spraying them with water. Under these conditions apples appearing entirely normal when picked have developed serious arsenical injury within a short time. An example may be cited of a crop of Winesap packed wet during the latter part of October, 1926, and stored in a poorly ventilated basement. Seventeen per cent developed this arsenical injury by the middle of December, whereas only about 1 per cent of the fruit from the same lot, placed in cold storage at the same time, developed arsenical injury during the same period. The decreased injury was apparently due to the drier atmosphere of the cold-storage room.

Arsenical injury of this type has been repeatedly produced experimentally at the Wenatchee laboratory. Heavily sprayed apples were packed in 50-pound lard cans with tightly fitting covers that prevented ventilation or evaporation. These were held in cold storage under the same conditions as similar fruit packed in ordinary apple boxes. Typical results of these experiments are presented in Table 1.

TABLE 1.—*Arsenical injury produced on stored apples*

Lot No.	Variety and year	Condition when packed in—		Arsenical injury at calyx
		Tight can	Ordinary box	
				Per cent
1	Jonathan, 1919	Wet		81.5
2	do	Dry		25.4
3	do		Wet	0
4	do		Dry	0
5	Winter Banana, 1928	Dry		47.8
6	do		Dry	0

In the case of the Jonathans packed dry in tight cans in 1919, injury developed in storage only after they had become wet from condensation of transpired moisture. However, the injury was less than one-third that of the lots which were wet when packed. The marked increase in the amount and severity of injury noted in lot 1 over that shown for lot 2, where the only difference was in the amount of moisture, indicates that the presence of moisture rather than CO_2 is the deciding factor. This is in agreement with the findings of Haywood and McDonnell (*6*) and Patten and O'Meara (*10*), who investigated the influence of CO_2 on arsenical injury of foliage.

It has also been shown by various investigators (*6*, *7*, *9*) that in the presence of small quantities of alkaline materials the amount of soluble arsenic derived from lead arsenate sprays is greatly increased. An excess of lime is effective in preventing such injury, since it combines with the soluble arsenic to form calcium arsenate, which is relatively insoluble and nontoxic to plant tissue. Many of the soils of the arid apple-growing district of the Pacific Northwest are alkaline, and incrustations of various alkaline salts are often found along the irrigation furrows in the orchards. At harvest the apples carry deposits of soil dust as well as residue of lead arsenate spray. This

undoubtedly contributes to the occurrence of arsenical injury at the calyx of the apples.

That this injury occurs only after penetration of soluble arsenic into the fruit tissues, as already shown by Mogendorff (*9*) to be the case in leaf injury, was demonstrated in a series of chemical studies conducted at this laboratory.

Representative lots of uncleaned apples direct from the orchard, all showing deep killing of tissues at the calyx, were selected. The injured parts were dissected out and carefully peeled to eliminate surface deposits. The sample was then weighed and leached for 24 hours with distilled water, after which calculations of arsenic as arsenic trioxide (As_2O_3) were made on the leachings by the Gutzeit method.[2] Typical results of such determinations are presented in Table 2.

TABLE 2.—*Soluble arsenic calculated as As_2O_3 in injured tissue of apples taken directly from the orchard, Wenatchee, Wash., 1928*

Lot No.	Variety	Arsenic in 1,000 grams of fresh tissue	
		Injured	Normal [1]
		Milligrams	*Milligrams*
1	Yellow Newtown	6.96	0
2	Rome Beauty	4.10	0
3	Winesap	2.63	0

[1] Adjacent to injured tissue.

Similar analyses were made to determine whether arsenic could likewise be found in the tissues of apples upon which the injury appeared after washing. The results are presented in Table 3.

TABLE 3.—*Soluble arsenic calculated as As_2O_3 in apple tissue injured after being subjected to various washing processes, Wenatchee, Wash., 1928*

Variety	Solution used in washing	Arsenic in 1,000 grams of fresh tissue	
		Injured	Normal [1]
		Milligrams	*Milligrams*
Jonathan	Hydrochloric acid, 0.35 per cent	9.44	0
Winesap	do	2.63	0
Do	A commercial preparation composed of borax, sodium hydroxide, and sodium carbonate.	1.96	0

[1] Adjacent to injured tissue.

Further evidence that dissolved arsenic causes injury on apples was obtained from experiments in which nonsprayed Winesap apples were dipped in solutions of arsenic pentoxide (As_2O_5) and packed without rinsing or drying. These were held in ordinary cool storage. The results of this experiment are presented in Table 4.

[2] The writers are indebted to C. D. Dolman, chemist of the Department of Agriculture of the State of Washington, for the analytical work reported herein.

TABLE 4.—*Injury produced on arsenic-free Winesap apples by dipping them in solutions of arsenic pentoxide calculated as As_2O_5*

Arsenic in 100 cubic centimeters of water	Apples affected
Milligrams	*Per cent*
100	40
40	30
20	16
10	4
0	0

The injury did not begin to appear until 10 days after treatment, but continued to increase for several weeks. No injury occurred except around the calyx or in the stem basin, but sometimes both regions were affected.

Most of the injury was quite typical of that produced as a result of the washing process or that which occurs on heavily sprayed unwashed apples that become wet. Some of the apples in this experiment, however, were more severely injured, and the flesh at the calyx end was killed to a depth of a half inch or more. In such cases it was possible to secure good material for chemical analysis, and the amount of arsenic present in the injured flesh tissue was determined in the manner already described. In a typical case of this sort, 5.5 milligrams of arsenic calculated as As_2O_3 were found in 1,000 grams of fresh flesh tissue from the injured calyx region, whereas a control analysis of adjacent uninjured tissue gave negative results for arsenic.

Many washed apples found in storage with severe arsenical injury in the calyx upon analysis yielded less than 0.01 grain of arsenic (As_2O_3) per pound. Apparently, therefore, apples may be satisfactorily cleaned, so far as compliance with legal regulations is concerned, and still retain sufficient arsenic in the calyx region to kill the skin and underlying flesh tissue. The arsenic apparently is not always completely removed in the washing process, or the apples may take up additional quantities of soluble arsenic in their passage through washing solutions heavily charged with dissolved arsenic.

In studying the latter possibility, the accumulation of dissolved arsenic in a continuously used washing solution was determined during a 10-hour run. During the day 1,250 boxes of Winesap apples were washed, and samples of the hydrochloric acid were taken at intervals. The results are shown in Table 5.

TABLE 5.—*Accumulation of dissolved arsenic calculated as As_2O_3 in 0.77 per cent hydrochloric acid solution during 10 hours' washing of 1,250 boxes of Winesap apples*

Time	Arsenic per 1,000 cubic centimeters
	Milligrams
7.00 a. m.	Trace.[1]
10.00 a. m.	172.5
12.00 m.	275.0
3.30 p. m.	402.5
6.00 p. m.	550.0

[1] Commercial hydrochloric acid was used in which traces of arsenic occur.

The extreme difficulty of rinsing solvent solutions from the calyx region is attested by all who have had any experience in the washing of apples. Since machines with solid jet sprays forced the solvent deep into the calyx, frequently causing excessive loss from arsenical injury, it was soon found necessary either to modify them or to abandon their use.

METHODS OF PREVENTION

When apples are thoroughly cleaned, arsenical injury may be almost entirely prevented by the use of copious quantities of fresh rinse water. If any of the rinse water has to be recirculated, fresh water, as a spray under pressure, should be applied to the apples just as they leave the machines. The commercial adoption of this practice has prevented a large percentage of arsenical injury in the major apple-growing districts of the Pacific Northwest.

Many operators do not have access to a water supply which provides adequate rinsing facilities. Experiments were conducted to determine the best way to meet this situation. Injury to apples submerged for three minutes in a 1 to 1,000 solution of arsenic pentoxide was compared with injury to comparable apples dipped in similar solutions neutralized by the addition of sodium bicarbonate, calcium carbonate, calcium hydroxide, and magnesium carbonate, respectively. The apples were not rinsed but were packed and sorted in the usual manner and examined after 10 weeks of storage.

When apples were submerged in arsenic pentoxide, 1 to 1,000, and not rinsed, 40 per cent showed injury. When sodium bicarbonate was used to neutralize the arsenic pentoxide, 22 per cent of the apples showed injury. When calcium carbonate, calcium hydroxide, or magnesium carbonate was used to neutralize the arsenic pentoxide, no injury appeared on any of the apples.

The reaction between arsenic pentoxide and sodium bicarbonate produces sodium arsenate, which is almost as toxic as the arsenic pentoxide itself. On the other hand, the reactions between arsenic pentoxide and lime and the other materials tested produce compounds that are relatively nontoxic to plant tissues.

The practical application of the principle demonstrated in this experiment has been proved repeatedly in commercial operations. The use of lime in the rinse water is now a standard procedure in packing houses where the water supply is curtailed or where extra precaution against injury is desired.

A number of experiments were conducted to determine how lime can be used in the rinse water without leaving an objectionable residue on the apples after they are dried. It was found that when commercial hydrated lime was used, 3 pounds to 100 gallons was as much as could be employed without leaving a residue. When quicklime was used it had to be completely slaked and prepared as milk of lime before adding to the rinse water in order to obtain satisfactory results. When employed in this manner, and in the proportion of 2 pounds to 100 gallons, it was found to be preferable to the commercial hydrated lime.

HYDROCHLORIC-ACID INJURY

With the general adoption of hydrochloric-acid washes for the removal of lead arsenate residue, it was anticipated that there would be more or less chemical injury to the fruit, especially at the hands of people inexperienced in the use of chemicals.

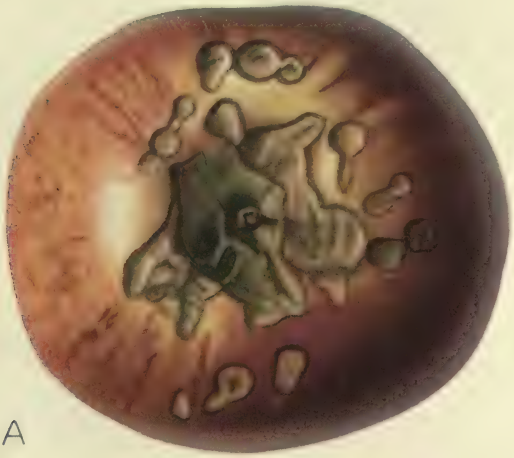
The character of hydrochloric-acid injury to apples was early determined in laboratory experiments. This injury causes a bleaching of the skin, frequently accompanied by a cracking through the center of the affected area. With age, the injured area becomes depressed but remains a light tan or yellowish color. If arsenic is present, the spots turn black.

Apples may be left in a 3 per cent solution of hydrochloric acid (9 gallons of the commercial acid made up to 100 gallons of water) for as long as 3 minutes at a temperature of 70° F. without injury, provided thorough rinsing in fresh water follows immediately; apples also can be left in a 0.33 per cent solution of hydrochloric acid for 9 or 10 minutes at 70° without injury, if thoroughly rinsed immediately after removal from the acid. Prolonged exposure to the acid invariably results in injury, as does neglect of rinsing. Traces of acid to the extent of even 0.05 per cent may remain in the rinse water without producing any symptoms of hydrochloric-acid injury. On the other hand, as already noted, the use of acidified rinse water markedly increases injury from any arsenic that may not be removed in the washing process.

The injury from hydrochloric acid, except when apples remain in it for prolonged periods, is limited to the location of the acid remaining on the fruit. The stem and calyx cavities are most frequently injured, but wherever drops of the acid solution are retained evaporation of the water causes the acid to become concentrated, and the injury usually results at such points. (Pl. 3.)

The severity and extent of typical hydrochloric acid injury apparently is not influenced by the temperature at which the washing solution is ordinarily used.

The hydrochloric acid injury described herein was encountered only occasionally and except for isolated cases was never found to be a factor of importance in commercial operations. This is in accord with the results of other investigations on washing methods, which have shown that when apples are properly washed and rinsed no acid injury was encountered (*1*).



A

B

Litho. A. Hoen & Co., Inc.

A.—Hydrochloric acid injury on Winesap apple

B.—Chemical injury on Jonathan apple from alkaline washing solution

INJURY FROM ALKALINE SOLVENTS

While hydrochloric acid is the solvent most commonly used for the removal of arsenical spray residue, a number of alkaline materials, including solutions or mixtures of sodium hydroxide, sodium carbonate, trisodium phosphate, borax, and other substances, are also employed. These solvents are sometimes used at a temperature of 100° F., or higher.

Arsenical injury, as already stated, occurs somewhat more commonly on apples washed in alkaline solvents than on those washed in hydrochloric acid. Because the alkaline solvents are much more difficult to rinse off than is the hydrochloric acid solution, apples washed in the former often retain some of the solvent in the calyx cavity, where it continues to react with residual lead arsenate, forming the injurious soluble arsenic.

Occasionally the alkaline solution itself causes chemical injury. Such injury is usually localized around the stem or calyx but is sometimes found at the lenticels as well. It is shown by the effect on the skin, which becomes dry and papery, tightly stretched, but seldom cracked, as in the case of hydrochloric acid injury, and is often torn loose from the underlying fleshy tissues. The color is yellowish or brownish yellow, except when a considerable quantity of arsenic is present, in which case the color becomes dark brown or black. (Pl. 3.)

INJURY AT THE CORE

In certain methods of washing some loss is caused by penetration of the washing solutions into the core through the open calyx tubes. This was especially true in early types of washing machinery in which the apples were submerged to a depth of several feet. It has also been found that submersion to a depth of 6 inches or more in washing solutions may result in core penetration. In other methods of washing, in which apples are not turned in their progress through the machine, those passing through with the calyx up so that it can be filled like a bottle are also likely to show some core penetration. The chemical injury to the core tissues is not in itself a matter of much importance, but the fungous spores introduced with the washing solutions cause core rot. (Pl. 2, B.)

Certain varieties of apples are commonly characterized by a rather large proportion of open calyx tubes. Among these may be mentioned Jonathan, Esopus Spitzenburg, Stayman Winesap, Ortley, and Delicious. On the other hand, such varieties as the Winesap, Yellow Newtown, Rome Beauty, and Winter Banana seldom have open calyx tubes. Varieties in the latter group may be washed with comparatively little danger from core rots, whereas with the former group due consideration should be given this factor in the selection of washing methods.

HEAT INJURY

It has been found that when apples are submerged in solutions heated to 100° F., or higher, for periods of three minutes or longer, there is considerable danger of injury to the fruit. The results of this injury usually appear within 10 days or two weeks in the de-

velopment of latitudinal cracks around the calyx, often continuing lengthwise on to the cheek of the apple. (Pl. 2, C.) Only where considerable arsenic is dissolved in the washing solution does the cracked skin become blackened. Characteristically it is grayish or yellowish in color, resembling hydrochloric-acid injury, for which it might be mistaken. It may be produced, however, by the use of heated water alone.

Apples are somewhat more susceptible to this type of injury at the time of harvest than after being kept for several weeks. Fortunately, it is generally not necessary to use heated solutions at this time, unless unusual spray practices have been followed. Likewise, few washing methods or devices require exposure of the fruit for a period long enough to cause injury, even when heated solutions are used. Heat injury is a factor that must be considered chiefly in connection with dipping tanks or other homemade devices used in small-scale operations.

INFLUENCE OF WASHING ON STORAGE ROTS

Aside from rots due to penetration of washing solutions into the core region and those occurring at points of chemical injury, it has been found that loss from storage rots may be somewhat more prevalent on washed than on unwashed apples. The extent of this loss varies with the amount and character of the handling to which the fruit is subjected. The number of bruises and injuries is generally increased on apples during the washing process on account of the extra handling involved. The apples are never entirely dry when packed, and the moisture they hold also favors the development of rots by providing suitable conditions for the germination of fungus spores.

Large numbers of fungus spores are removed from the apples and accumulate in the solutions during the washing process. The washing solutions have little or no toxicity for these spores and may spread infection. This hazard can be greatly reduced by sorting out rotted apples before the fruit is washed.

No practical method has been found of disinfecting the apples during the washing process. The accumulation of spores in the washing machinery, however, can be reduced by discarding solutions after each day's run or after the washing of about a thousand bushels. The machines should then be thoroughly scrubbed out with clean water. Where live steam is available, it can be utilized effectively to disinfect the machines. Disinfection may also be accomplished by adding 1 pint of commercial formalin to each 100 gallons of washing or rinsing solution after each day's run. The formalin solution should be pumped through the machine for 5 or 10 minutes and allowed to stand overnight before being replaced by fresh washing solutions for the next day's operations.

However, the most important factor in the prevention of loss from storage rots is careful handling of the fruit to avoid bruising or puncturing the skin. This is imperative at all times. The hazard can also be reduced by drenching the apples as they leave the machine with copious quantities of fresh rinsing water under pressure.

CONCLUSION

The injuries herein described should not be understood to represent extreme hazards involved in all fruit-washing operations. This bulletin is rather an attempt to record the types of injuries that may be encountered and the experimental work which has been done to explain their nature as well as to determine methods of prevention. It is the general conclusion of all those familiar with the spray-residue problem that if washing is done with proper equipment and with due care under desirable sanitary conditions, neither the market value nor the keeping quality of the apples will be impaired; on the contrary, they may even be enhanced.

SUMMARY

Calyx scald is primarily caused by the presence of soluble arsenic on the apples. This was proved by producing the injury by application of soluble arsenic to the apples and by isolating soluble arsenic from the injured tissues.

This injury occurs on unpicked apples in the orchard and on uncleaned picked apples that have become wet, but most commonly on apples that have been subjected to washing processes. Its occurrence follows the use of either hydrochloric acid or alkaline solvents as washing materials.

Chemical injuries to apples from hydrochloric acid and alkaline solvents are described and differentiated from the injury caused by soluble arsenic. These injuries have been found only occasionally and rarely cause commercial losses.

The prevention of injury from soluble arsenic and from various chemical solvents commonly used in washing apples depends primarily on the adequate rinsing of the fruit with clean water. Where sufficient water is not available, the addition of lime to the rinse water is beneficial.

Core rots are increased by methods of washing that permit solutions contaminated with fungus spores to penetrate through open calyx tubes. Varieties commonly characterized by open calyx tubes, therefore, should be washed by methods that do not cause penetration.

Injury may result when apples are held in solutions heated to 100° F. or higher for periods of three minutes or longer. Apples are more susceptible to this injury at the time of harvest than after being kept for several weeks.

Loss from storage rots may be somewhat greater on washed apples, owing to the extra handling to which they are subjected. Careful handling to avoid bruising or puncturing the skin, and the use of copious quantities of fresh rinsing water under pressure are important factors in reducing losses from storage rots.

Where the washing is properly done, the market value and the keeping quality of apples are not impaired and may even be improved.

LITERATURE CITED

(1) DIEHL, H. C., FISHER, D. F., HARTMAN, H., MAGNESS, J. R., and ROBINSON, R. H.
1929. REMOVAL OF SPRAY RESIDUE FROM APPLES AND PEARS IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Circ. 59, 20 p.

(2) FISHER, D. F., and REEVES, E. L.
1927. SOME EFFECTS OF CLEANING TREATMENTS ON THE KEEPING QUALITY OF APPLES AND PEARS. Wash. State Hort. Assoc. Proc. 23: 163–175, illus.

(3) ———
1928. THE INFLUENCE OF CLEANING TREATMENT ON STORAGE DISEASES OF APPLES AND PEARS. Idaho State Hort. Assoc. Proc. 33: 87–103, illus.

(4) GILLETTE, C. P.
1888. ARSENIC EXPERIMENTS. Iowa Agr. Expt. Sta. Bul. 2: [30]–35.

(5) ———
1890. EXPERIMENTS WITH ARSENITES. Iowa Agr. Expt. Sta. Bul. 10: [401]–420.

(6) HAYWOOD, J. K., and MCDONNELL, C. C.
1910. LEAD ARSENATE. U. S. Dept. Agr., Bur. Chem. Bul. 131, 50 p., illus.

(7) HEADDEN, W. P.
1908. ARSENICAL POISONING OF FRUIT TREES. Colo. Agr. Expt. Sta. Bul. 131, 26 p., illus.

(8) MCDONNELL, C. C., and GRAHAM, J. J. T.
1917. THE DECOMPOSITION OF DILEAD ARSENATE BY WATER. Jour. Amer. Chem. Soc. 39: 1912–1918, illus.

(9) MOGENDORFF, N.
1925. SOME CHEMICAL FACTORS INVOLVED IN ARSENICAL INJURY OF FRUIT TREES. N. J. Agr. Expt. Sta. Bul. 419, 47 p., illus.

(10) PATTEN, A. J., and O'MEARA, P.
1919. THE PROBABLE CAUSE OF INJURY REPORTED FROM THE USE OF CALCIUM AND MAGNESIUM ARSENATES. Mich. Agr. Expt. Sta. Quart. Bul. v. 2, no. 2, p. 83–84.

(11) VOLCK, W. H.
1911. THE SIGNIFICANCE OF LEAD ARSENATE COMPOSITION. Science (n. s.) 33: 866–870.

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THE RELATION OF SEASON OF WOUNDING AND SHELLACKING TO CALLUS FORMATION IN TREE WOUNDS[1]

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CONTENTS

	Page		Page
Introduction	1	Discussion of results—Continued.	
Review of literature	2	Effect of season of wounding as shown by shape of callus	19
Experimental methods and procedure	3	Effect of shellac as shown by area of callus	19
Reason for testing shellac	6	Effect of shellac as shown by shape of callus	22
Results expressed in diagrams of callus growth	8	Effect of vigor on healing	25
Results expressed as average area of callus growth	15	Fungus growth on the wounds	25
Discussion of results	18	Application of results	26
Effect of season of wounding as shown by area of callus	18	Summary	27
		Literature cited	28

INTRODUCTION

The decorative and esthetic value of beautiful shade trees has ever been appreciated by civilized man, and the question how best to protect such trees from the ravages of time undoubtedly dates back to very early days. In the past few years, the public has apparently become more interested in matters relating to the care of shade trees than formerly. Commendable effort has been directed toward the improvement of existing practices and the development of better ones.

Among the many practices in which improvement has been sought are those relating to pruning, since upon pruning depends in large measure the degree of success with which trees may be adapted to habits and sites that are foreign to them in nature. It plays a rôle in treatment of their damage by weather, insects, and fungi. Since the usefulness, beauty, or health of the shade tree often depends in part upon the skill with which it is pruned, numerous problems arise

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regarding the best performance of the task. The present work has been undertaken in an effort to shed light on that question so frequently asked, "When is the best time to prune shade trees?"

The idea underlying the present investigation first suggested itself in the course of some preliminary experiments in the use of wound dressings. This is a phase of the pruning problem which has occasioned much controversy, since a review of the literature shows not only frequent disagreement among different writers but even in the results of the same writer as to the merit of the various materials employed in treating tree wounds. The author's observations suggested the likelihood that some of these apparent discrepancies might be due to differences in the seasons at which the pruning was done and the dressings applied. In this possibility lies the basis of the present investigation, in which are considered the area and shape of callus produced by both treated and untreated wounds on forest trees, with the purpose of applying the results to practical pruning and cavity work of shade trees.

REVIEW OF LITERATURE

The literature of pruning in general contains voluminous references in regard to the best time to prune. There are, however, conflicting opinions. At one extreme there are adherents of Long (*10*),[3] who said, "As to the time [of pruning], the advice of the successful old gardener, to prune when your knife is sharp, would be hard to improve upon"; and at the other extreme are those who stipulate some definite season as the only one suitable for cutting. In the main, investigators and general practice alike tend to favor pruning during the dormant period, but even the results of such outstanding work as that of Bedford and Pickering (*2*, *p. 37–38*) in England, of Chandler (*4*, *p. 41–43*) in New York, and of Brierly (*3*) in Minnesota do not point to appreciable advantage in pruning at any particular time during this dormant period.

Somewhat different are the conclusions of Rose (*13*), based on his study of pruning wounds of apple trees in Missouri. He writes:

> The poorest time to make large pruning wounds, in Missouri orchards, is in winter. Wounds made then heal slowly and are very likely to become infected with cankers. The best time to do such pruning is some time during the period from March to June, inclusive, preferably in May or June on account of the lessened danger then from canker infection and bark injury around the wound.

Wiltshire (*16*, *p. 190*), in his study of wound dressings discovered somewhat the same condition existing in England, as evidenced by his statement:

> On June 8 the wounds made on April 29 were found to be much further advanced in healing than those made on February 10, a somewhat astonishing result.

Corbett (*6*, *p. 19*) states:

> Convenience and climatic conditions must be taken into consideration in determining the period for pruning. In the removal of large branches, however, the work should be done at a season when growth is at its height, in order that the healing process may begin at once and continue as long as possible during the season in which the cut is made.

[3] Italic numbers in parentheses refer to Literature Cited, p. 28.

Bailey (*1*, *v. 5*, *p. 2821*) has summed up the situation, both from the standpoint of the healing of the wound and from the practical aspect of its making, by saying:

> So far as the healing of the wound is concerned, it is perhaps best to prune when the vegetative activities begin in spring so that the wound is quickly covered or "healed." For the purpose of checking growth and producing other definite results, it may be necessary to prune at other times of the year. As a general rule, however, the best time to prune is late autumn or early spring, when labor can be had and before the rush of spring work comes on. In practice, it resolves itself largely into a question of the convenience of the operator.

The pruning problem in this country is stressed chiefly in connection with ornamental and horticultural trees.

In Europe matters relating to pruning have been given considerable study by European foresters. Zederbauer (*17*) experimented with *Fagus sylvatica*, *Quercus pedunculata*, *Q. sessiliflora*, *Pseudotsuga douglasii*, and *Picea excelsa*. As a result of a study in which he measured the callus produced following the removal of branches, he concluded that pruning of forest trees is least injurious when carried on in early spring.

Swarbrick (*15*), an English investigator, has studied histological changes that take place during the healing process. His work does not treat of callus formation, but relates to the blocking of the wood vessels by the deposition of gum in the region of the wound. Working with sycamore, rhododendron, plum, and apple, his method consisted in clipping off the ends of branches at a point where they were approximately three-quarters of an inch in diameter, the cut surface being smoothed with a knife and left exposed. For each species a series of such wounds was made each month for a year, and subsequent to each treatment branches were cut off for study at monthly intervals. Microscopic examination showed that during the growing season the tracheae became plugged with a deposit of viscous substance of an unknown chemical nature, referred to as "wound gum," whereas during the dormant season no complete blocking took place. Swarbrick stated, therefore, that "the experimental results would appear to favor the practice of spring and summer pruning so far as the natural closure of the cut surface against disease is concerned." Priestley (*12*), under whose direction Swarbrick's research was performed, has given a brief, less technical account of the study.

EXPERIMENTAL METHODS AND PROCEDURE

The study was conducted at the Yale Forest Preserve, Woodbridge, Conn., in an open, mixed hardwood stand (fig. 1), on a tract slightly sloping to the south. The soil is a stony clay loam overlying a bed rock of chlorite schist. Because of competition for soil moisture and for light, the environment of the trees in this area seemed less favorable than that of well-planted specimen shade trees, but more favorable than the adverse environment of many trees planted for street and park purposes.

A total of 30 trees, exclusive of check trees, was used in the experiment proper, 5 trees being selected of each of the following six species:[4] Red maple (*Acer rubrum* L.), black oak (*Quercus velutina* Lamarck), chestnut oak (*Q. montana* Willd.), red oak (*Q. borealis*

[4] Nomenclature from Sudworth (*14*).

maxima (Marshall) Ashe), white oak (*Q. alba* L.), and yellow poplar (*Liriodendron tulipifera* L.).

These species were used because they were well represented in the particular stand and because the trees of these species often receive treatment. Individuals within the species were not selected for vigor but were taken as they grew on the site in order that both vigorous and weak specimens might be included in the study.

At the time the experiment was laid out the smallest tree was 5.6 inches in diameter at breast height, the largest 12.7 inches, and the average of all 30 trees 9.1 inches. (Table 1.)

FIGURE 1.—General view of the site used

TABLE 1.—*Trees used in the experiment*

Species and tree No.	Vigor of trees	Diameter breast high	Species and tree No.	Vigor of trees	Diameter breast high
Acer rubrum:		*Inches*	Quercus borealis maxima:		*Inches*
1	Fair	8.1	1	Good	9.5
2	do	10.2	2	do	7.6
3	do	10.6	3	do	12.7
4	do	8.4	4	do	7.6
5	do	11.4	5	do	9.1
Average		9.7	Average		9.3
Liriodendron tulipifera:			Quercus montana:		
1	Good	11.4	1	Good	10.0
2	do	10.0	2	do	9.4
3	do	9.4	3	do	8.6
4	do	11.8	4	do	7.6
5	Fair	9.4	5	do	8.6
Average		10.4	Average		8.8
Quercus alba:			Quercus velutina:		
1	Good	6.3	1	Good	10.0
2	Fair	9.5	2	Poor	5.6
3	Poor	9.5	3	Good	9.4
4	Very poor	5.9	4	Poor	7.3
5	Poor	7.6	5	Fair	9.4
Average		7.8	Average		8.3

The wounds were made with an auger in order to have them as nearly uniform as possible. They thus differed from wounds made by the removal of branches in that they presented cuts that were parallel with the grain of the wood rather than cut across the grain. The holes, 1½ inches in diameter, were bored through the bark and about one-half inch into the wood, care being taken to see that they were sufficiently deep to remove all the cambium tissue.

On each of the trees studied auger wounds were made on the 15th day of each month in the year. The work was begun on October 15, 1926. The holes were bored in pairs, the members of the pair being side by side with their centers approximately 3 inches apart. For each pair of holes, the left received no treatment, and the right was painted with shellac. Ridged or depressed areas were avoided, since growth at such locations sometimes varies much from the normal growth of the trunk as a whole.

The first pair of wounds were made near the base of the tree from 1 foot to 18 inches above the root collar. They were not placed at the same points of the compass for the several trees, but were varied on each tree so that any possible favorable growth effect of a particular aspect of facing might be disregarded. Each pair of wounds made in succeeding months was bored from 2 to 5 inches above, and to the right of the pair of the preceding month, so that the pairs spiraled upward about the trunk. At the completion of the work each of the 30 trees bore 12 pairs of wounds.

The nature of the experiment was such that each tree of a given species provided something of a check against the four other trees of the same species, and, to a lesser degree, a check against the trees as a whole. Comparison was also aided by the fact that paired wounds were used, although one of each pair had been coated with shellac and the other left untreated.

It appeared advisable to distribute the wounds of corresponding months so that any possible directional effect in their location around the trunk might be minimized. It might perhaps seem equally desirable to have distributed them more or less definitely with reference to height on the trunk. This was not done, however, partly because of the complexity that such arrangement would have introduced, and partly because there appeared to be little reason for suspecting marked variance in the callusing of wounds that differed only slightly in their vertical placement.

The correction of this latter assumption was demonstrated by check trees, one of which was used for each of the species in the experiment proper. On each of these check trees (fig. 2) six paired wounds were made with the auger precisely as described except for the fact that the wounds were all made on the same date (July 15, 1927), and that they were in line up and down the trunk rather than spiraled. Wounds of the check trees failed to show any material difference in rate of healing due to their location on the bole.

The first field notes were taken on July 15, 1927. Subsequent records were made on or within two days of the 15th of each month during the growing seasons of 1927 and 1928. Field records were taken on mimeographed forms. The circles on these sheets were 1½ inches in diameter, representing the full-sized outlines of wounds made by the bit. Two sheets were required for each inspection of

each tree. They were filled in with the number of the tree, its species, and the date of examination. Then, by means of numerous measurements, the outline of the callus of each wound was carefully sketched into its particular diagram. The wound and its diagram were next compared side by side, and the diagram corrected when necessary. In filling in these sketches the longer edge of the sheet was held parallel with the axis of the bole of the tree, the bottom of the sheet being toward the ground.

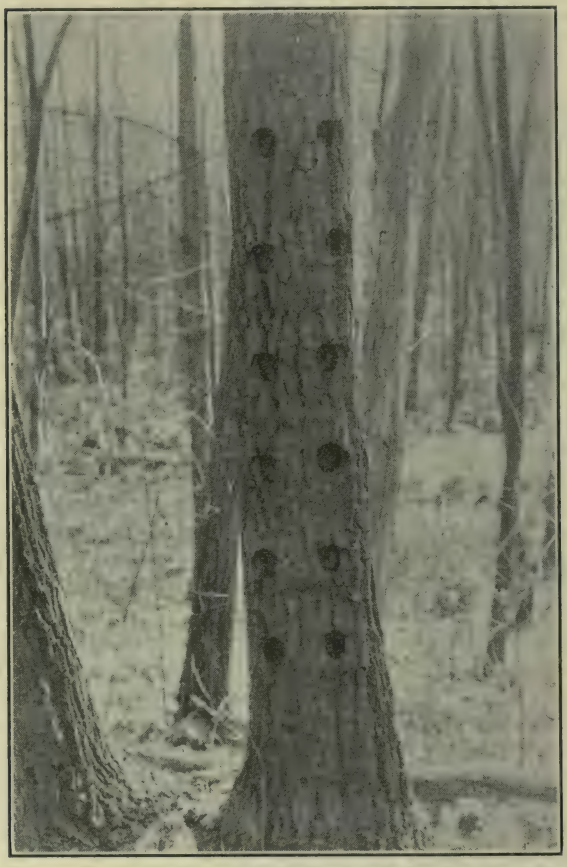

FIGURE 2.—A check tree of chestnut oak showing that the height at which the wounds were located on the boles did not affect the rate of healing

The field notes thus traced diagrammatically the closing in of the callus growth until the wound was completely healed (fig. 3) or until the experiment was terminated.

REASON FOR TESTING SHELLAC

In general practice, shellac has long been famed as a dressing for tree wounds. In Lindley's Theory of Horticulture (*9, f. n. p. 233*), which appeared in 1841, the following statement is made:

> A solution of Gum Shellac in alcohol, of the consistence of thin paste (put on with a brush), is an admirable application to wounds of stone-fruit trees, and others which are disposed to bleed profusely. It is readily applied, adheres closely, excludes the air completely, and is less offensive to the eye than large plasters of clay, composition, etc.

Durand (*7, p. 370*) in 1853 says:

> It will be well to have large wounds covered by a composition of gum shellac, dissolved in alcohol to the consistency of paint, and put on with a brush. This, I think, is as cheap and as good composition as can be had for closing pores of the wood—also protecting it from weather.

Howe (*8, p. 83*) in more recent studies used white lead, white zinc, yellow ocher, coal tar, shellac, and avenarius carbolineum on wounds of apple and peach trees. In summing up their effects on healing he stated:

Shellac seemed, the first season, to exert a stimulating influence upon the wounds used but the second season this effect disappeared. Of all the materials used shellac was least injurious. On the other hand it adheres to the wounded surfaces least well of all.

Collins (*5*), in his bulletin on tree surgery, recommends shellac as a dressing for scars less than one-half of an inch in width. On larger wounds he suggests its use as a protection to the cambium tissues against any drying out which might take place before the application of some more permanent dressing, such as tar or creosote, and to prevent possible chemical injury to the same tissues following the application of these substances. In a statement that healing of wounds by means of new callus growth at the sides is often more rapid if neither paint nor other generally used waterproof covering is applied, shellac alone is excepted.

Peets (*11*, *p. 31–32*), in his book on tree repair, says of shellac:

> Of the paint group, recent experiments indicate that shellac has great value. It is not a durable dressing but it seems to be entirely harmless to the cambium and to the young callus, which is not even true of white lead paint. Shellac has the further great advantages of drying very quickly and of being cheap and convenient. It ought to be in constant use when cavity work is being done in hot dry weather. A coat of shellac over the edges of an excision will often prevent the cambium from being killed back and the bark from separating from the wood, thus enlarging the wound.

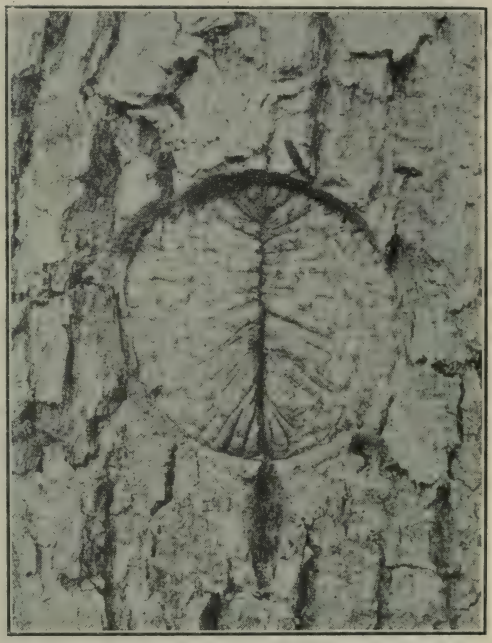

FIGURE 3.—A completely callused wound of white oak

In some unpublished experiments the writer has tried some 90 different materials as applications for wound dressings. Of these materials shellac seemed the most logical choice for this particular work. Beeswax, paraffin, "parapine wax," and grafting wax are also substances that could have been used. Dressings made with any of these latter materials are thicker and less transparent than applications of shellac. They were avoided because they would have masked results. In brief, shellac, despite its short life and consequent failure to afford adequate protection against the invasion of insect or fungus pests, is generally recognized as a material noninjurious to the development of callus.

The shellac used in these experiments was made by cutting dry orange shellac with alcohol denatured according to United States Internal Revenue Formula No. 1. The mixture was of the consistency of paint. A single coat was applied with a brush immediately after the wounds were made.

RESULTS EXPRESSED IN DIAGRAMS OF CALLUS GROWTH

To present diagrammatically the successive stages of callus development, the data for each individual tree were assembled upon a chart. Blank forms for this chart were drawn on tracing paper. The circles representing the outlines of the wounds were natural size. The several circles of the field notes were placed beneath their designated circles on the chart, and the outlines of the callus growth traced through the paper. In order to emphasize the areas of callus formation they were shaded. Where no shading occurs in the circle there had been no growth of callus; where the circle is completely shaded, callus had completely filled the wound. Several circles are

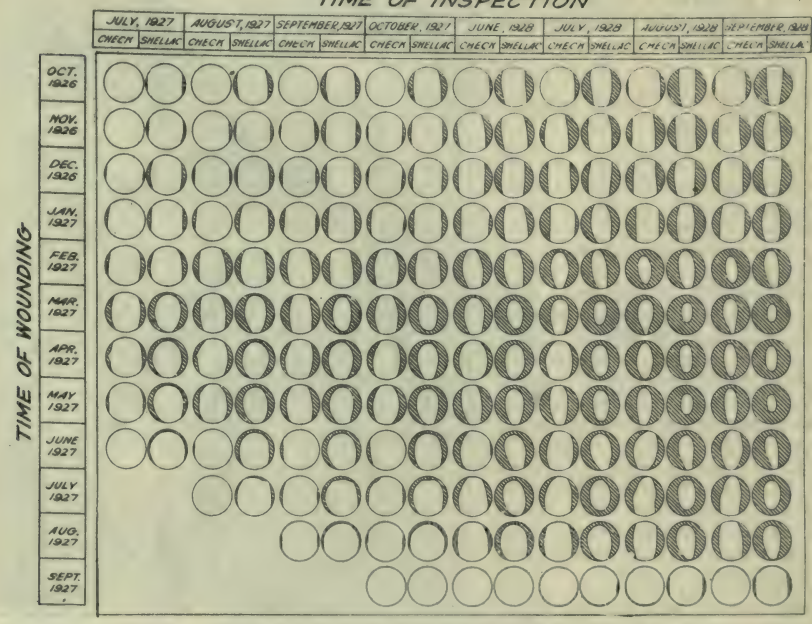

FIGURE 4.—Successive stages of callus growth for each wound on *Acer rubrum* No. 1

wanting in the lower left-hand corner of the chart, these wounds not yet having been made at the time the records were taken.

The completed individual diagrams of two trees of each species appear as shown in Figures 4 to 15, inclusive.

The tree worker is frequently more concerned with the shape of the callus than with the area of its growth. He has, in general, little difficulty in obtaining its satisfactory development at the sides of the wounds made by the removal of branches, through accidents to the bark, or in the cutting of cavities. The top and the bottom of the wound are slow to heal and prone to give trouble. This is especially true of the bottom of the wound, where healing is accomplished with difficulty, particularly if the wound is of considerable width. Dying back of the cambium at the top, and even to a greater degree at the bottom, is a frequent result. Even where considerable

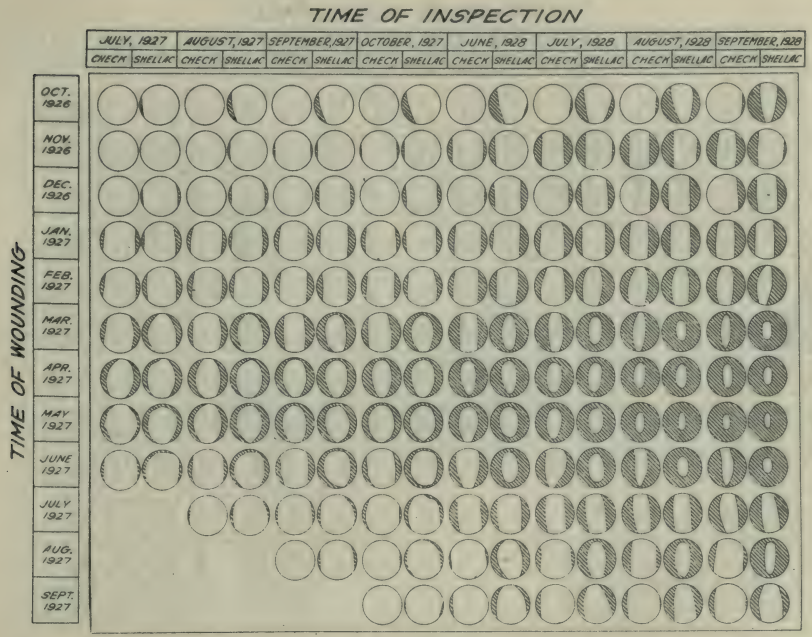

FIGURE 5.—Successive stages of callus growth for each wound on *Acer rubrum* No. 4

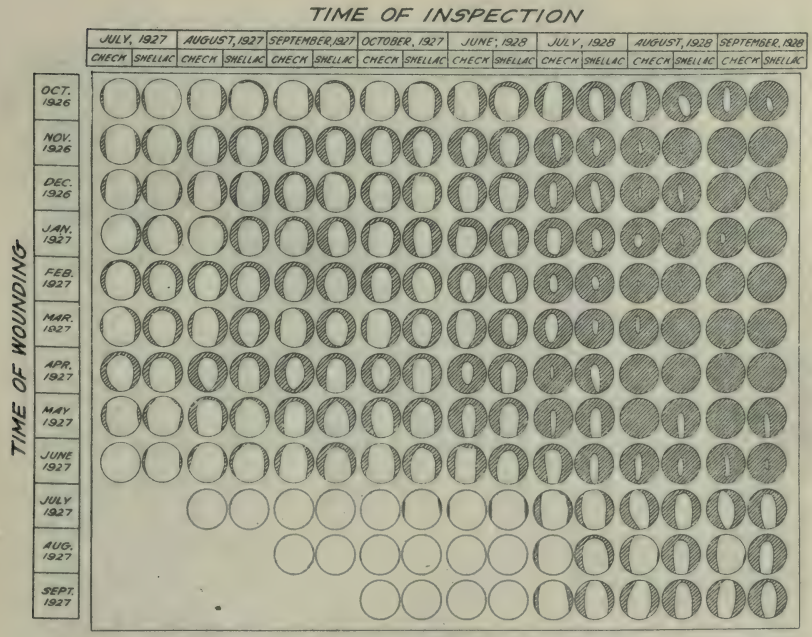

FIGURE 6.—Successive stages of callus growth for each wound on *Liriodendron tulipifera* No. 2

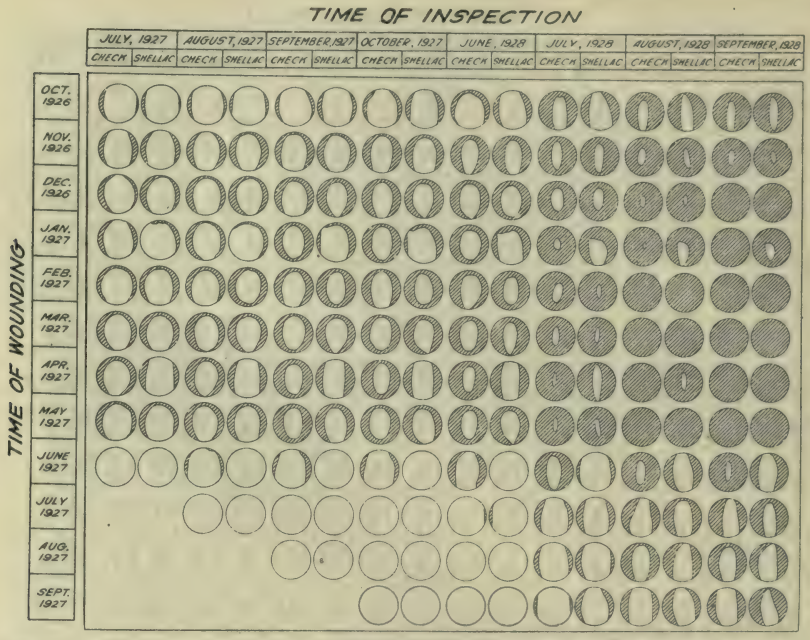

FIGURE 7.—Successive stages of callus growth for each wound on *Liriodendron tulipifera* No. 3

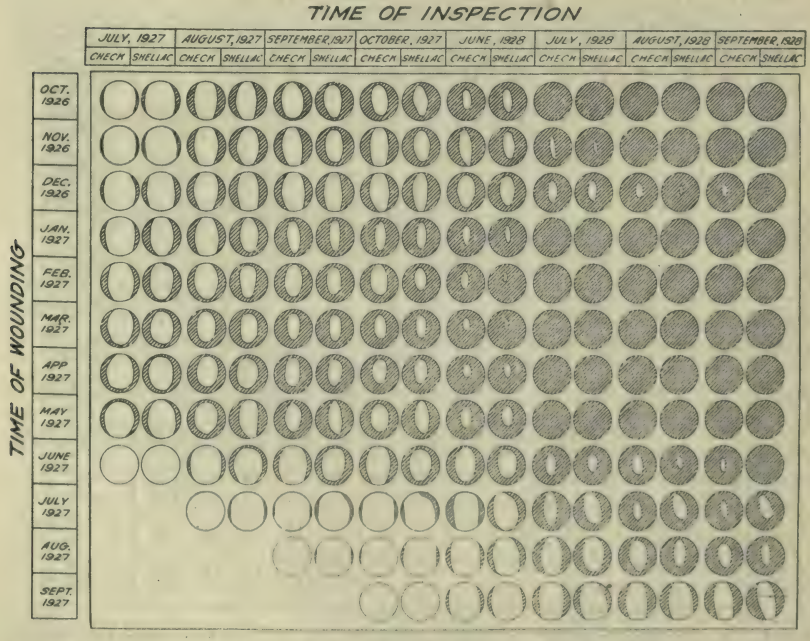

FIGURE 8.—Successive stages of callus growth for each wound on *Quercus alba* No. 2

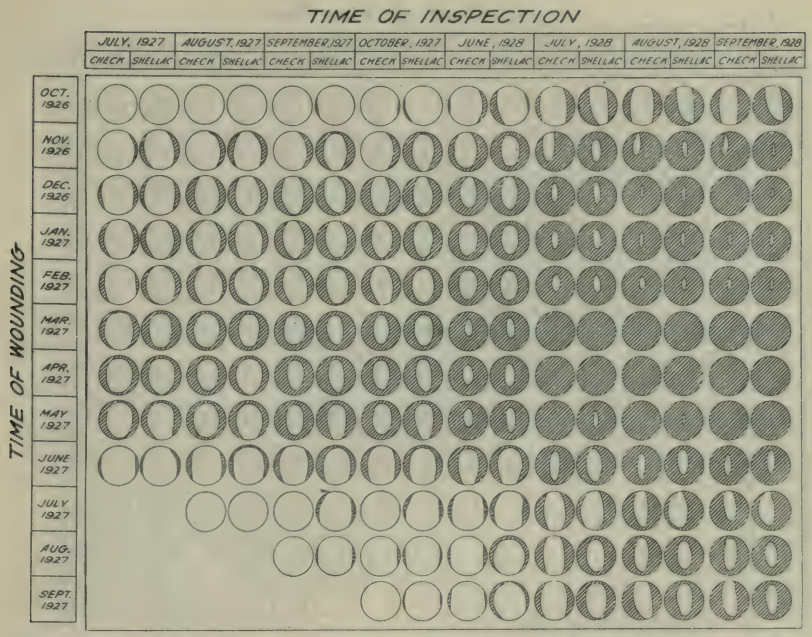

FIGURE 9.—Successive stages of callus growth for each wound on *Quercus alba* No. 3

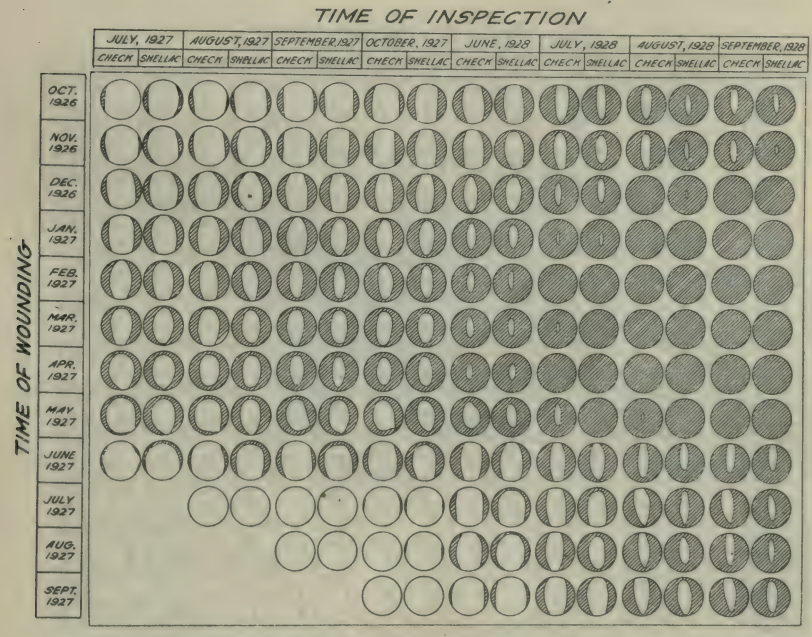

FIGURE 10.—Successive stages of callus growth for each wound on *Quercus borealis maxima* No. 3

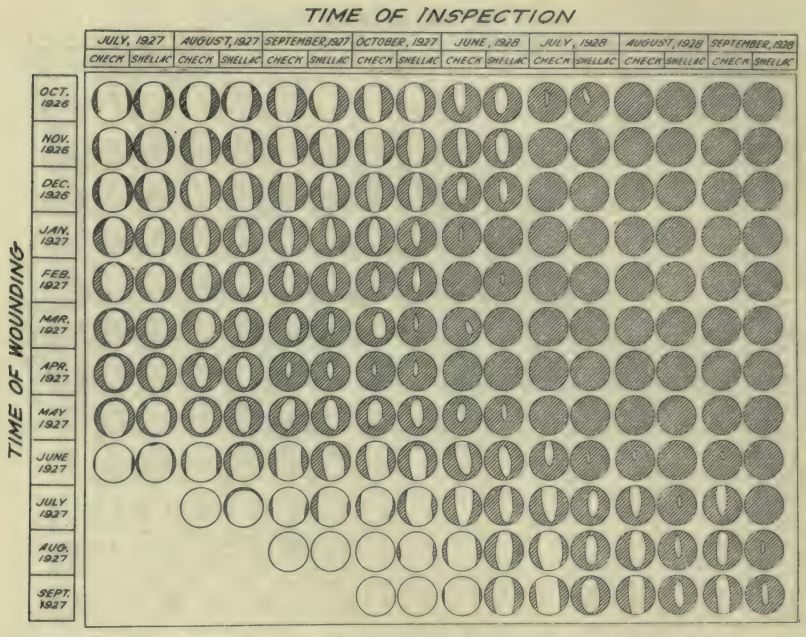

FIGURE 11.—Successive stages of callus growth for each wound on *Quercus borealis maxima* No. 5

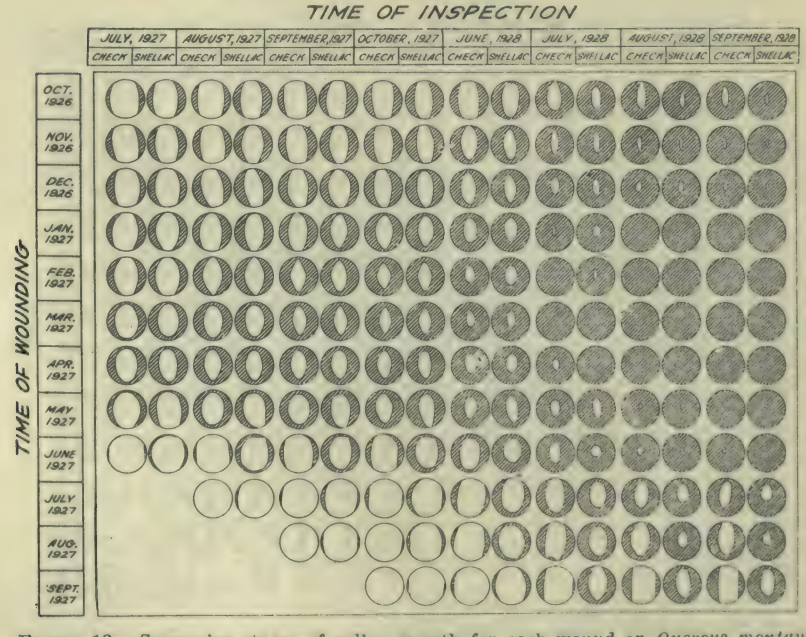

FIGURE 12.—Successive stages of callus growth for each wound on *Quercus montana* No. 3

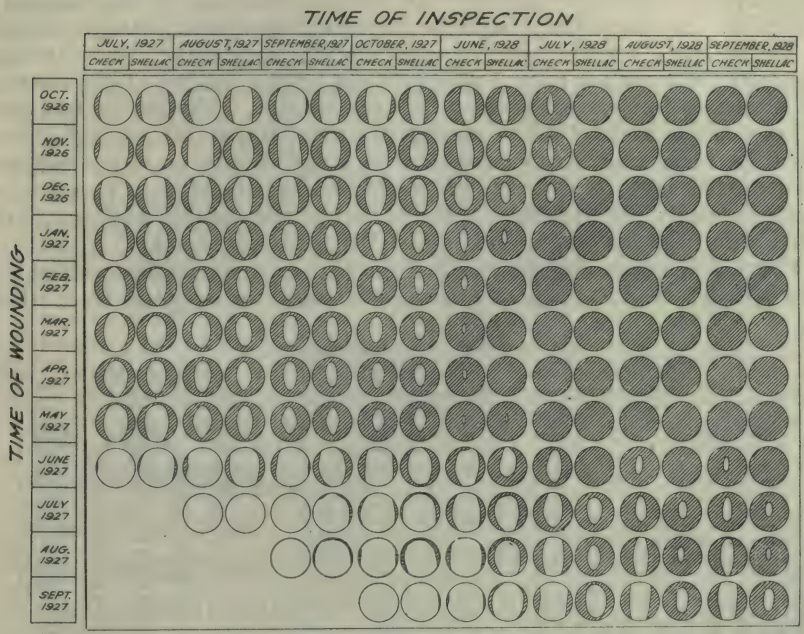

FIGURE 13.—Successive stages of callus growth for each wound on *Quercus montana* No. 4

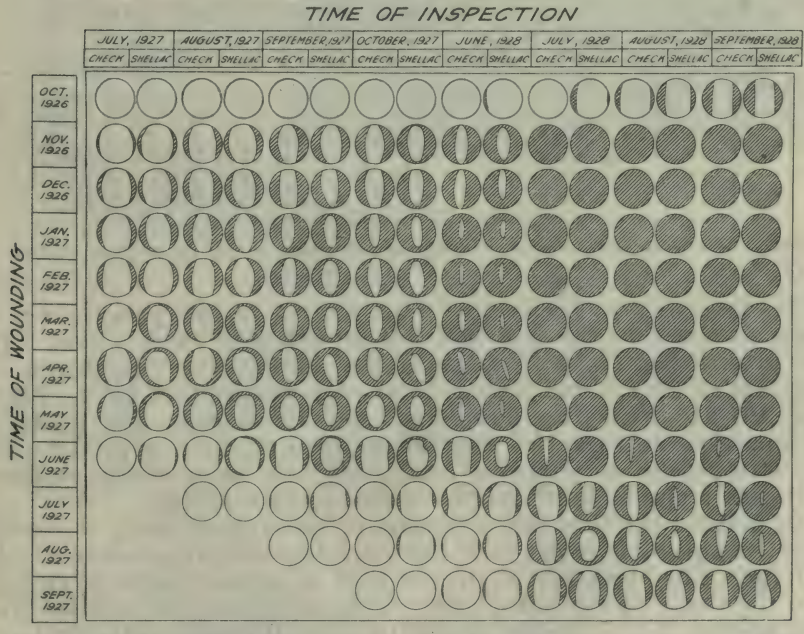

FIGURE 14.—Successive stages of callus growth for each wound on *Quercus velutina* No. 3

shaping is done, the difficulty of healing the base of the cut still presents a problem that requires the most careful handling.

The relatively slower growth and the tendency to kill back are not the only factors that play a rôle in making the healing of the bottom of the wound of importance to the tree worker. Fungus spores that collect on the face of the wound sometimes tend to be washed downward by rains and heavy dews and to lodge in any cracks or irregularities that may be present. Moisture collecting at such points aids the spores in germination and infection and assists the resulting mycelium in at least its initial attack on the outer wood.

From a diagrammatic presentation of the shape of the callus the tree worker is often able to interpret something of what took place

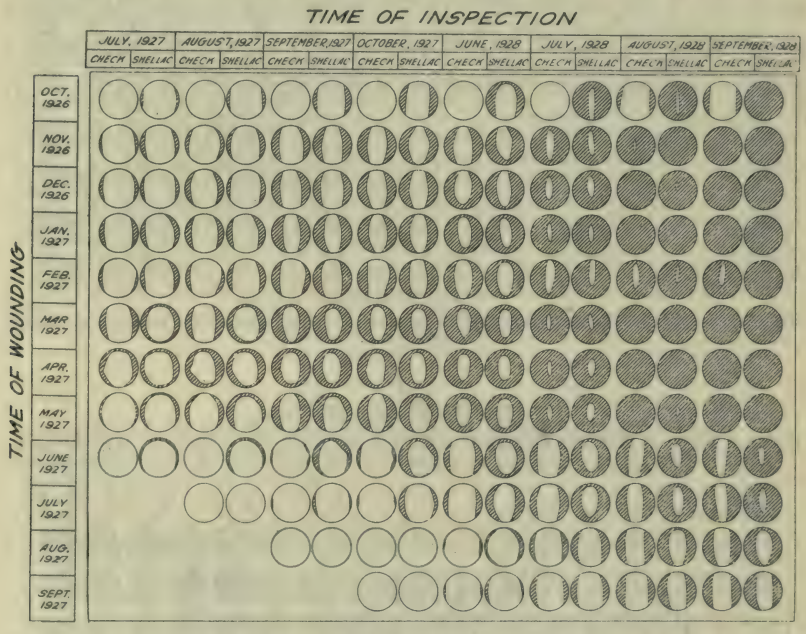

FIGURE 15.—Successive stages of callus growth for each wound on *Quercus velutina* No. 5

in the formation of the callus. This can not be interpreted from a mere statement of the area that this growth may have covered. If the growth has taken place along the sides of the wound and is wanting at the top and bottom he at once realizes that killing back (fig. 16) has taken place above and below the wound. The distance of separation between two such lateral areas of callus, together with the straightness or degree of curve of their inner edges, at once furnishes a clue as to the relative severity of the killing.

In making the field measurements of the present study it would have been possible to cut back the overlying bark from areas which had been killed back and to present both the actual degree of killing and the shape of the killed area. This procedure was avoided for two reasons: (1) It seemed highly probable that the cutting back of the bark would have changed the results of the experiments by producing further injury, followed by further dying back of the delicate

cambium tissues; and (2) even had it not endangered the results, the diagrammatic presentation would have required many times the already extensive space needed for giving the results pictured by the present method.

FIGURE 16.—Killing back on red maple

RESULTS EXPRESSED AS AVERAGE AREA OF CALLUS GROWTH

For convenience in averaging results, the callus growth was expressed in terms of the square inches of area that it covered. Such a practice, however, introduces a certain degree of error. For example, in Figure 17, the outlines of two wounds might be represented by the circles, growth of callus by the shaded areas, and a possible killing back in B by the dotted lines. Measuring shows that the areas of callus produced by A and B are equal, yet the healing represented by A is more desirable than that of B.

In calculating the numerical results all areas of callus were measured with a planimeter (fig. 18) from the full-sized charts. They were expressed to the nearest tenth of a square inch. Since the area of the 1½-inch wound used is approximately 1.8 square inches, measurements of the areas of callus ranging from no healing to complete healing read from 0 to 1.8 square inches.

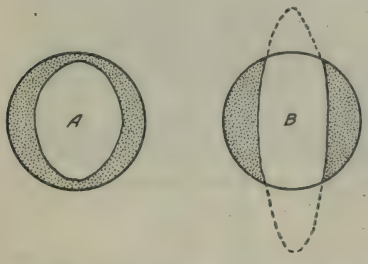

FIGURE 17.—Diagram showing that wounds with equal areas of callus do not always have equally desirable healing. The areas of callus of A and B are equal, but A represents more desirable healing than does B

After measurement, areas of callus of corresponding wounds were averaged. In each case the average represents five trees of the same species. These average figures appear in Table 2. Their arrangement corresponds to that of the diagram charts.

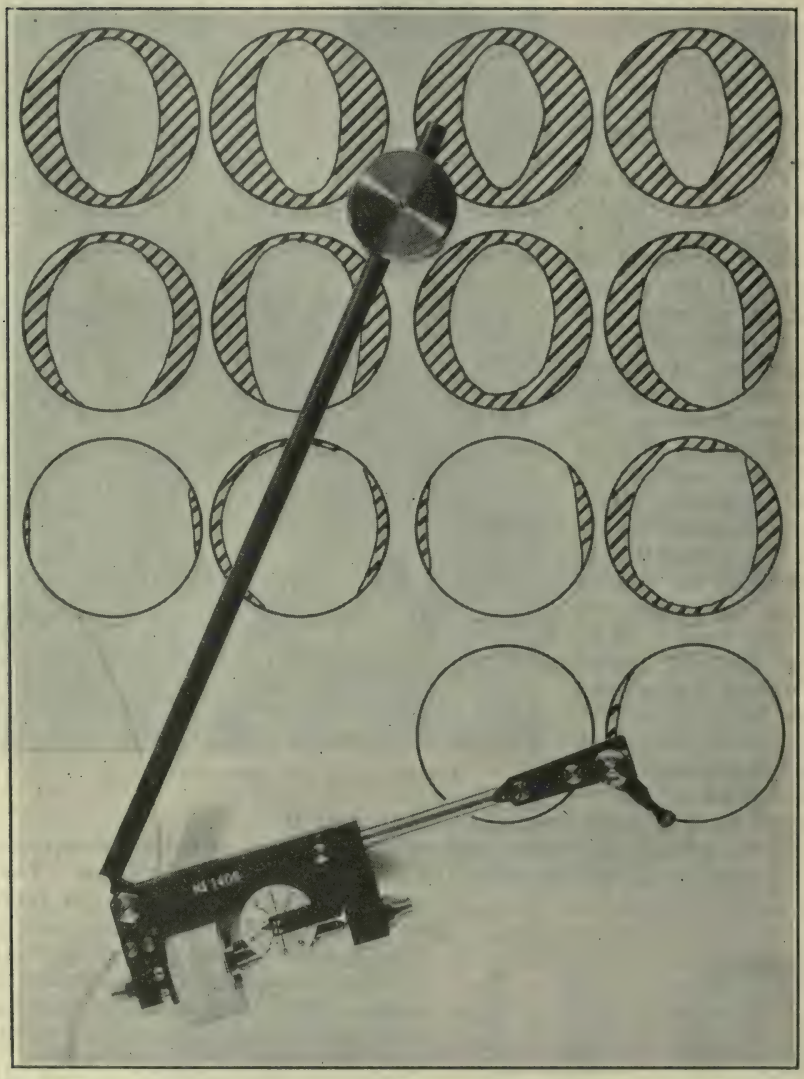

FIGURE 18.—Method of measuring the areas of callus with a planimeter

TABLE 2.—*Average areas of callus for five trees of each species*

[C=check wound; S=shellacked wound]

Species	Date wound was made	Square inches of callus on indicated dates															
		July, 1927		Aug., 1927		Sept., 1927		Oct., 1927		June, 1928		July, 1928		Aug., 1928		Sept., 1928	
		C.	S.	C.	S.	C.	S.	C.	S.	C.	S.	C.	S.	C.	S.	C.	S.
Acer rubrum	Oct., 1926	0.0	0.1	0.0	0.2	0.0	0.3	0.0	0.4	0.1	0.6	0.2	0.8	0.3	1.0	0.3	1.1
	Nov., 1926	.0	.1	.1	.2	.2	.4	.2	.3	.3	.5	.6	.6	.7	.8	.8	.9
	Dec., 1926	.1	.2	.1	.2	.2	.3	.2	.2	.3	.4	.6	.5	.7	.7	.6	.8
	Jan., 1927	.2	.2	.2	.3	.3	.4	.3	.4	.5	.6	.6	.7	.8	.9	.8	1.0
	Feb., 1927	.2	.2	.3	.4	.4	.5	.4	.4	.7	.7	.8	.9	1.1	1.0	1.0	1.1
	Mar., 1927	.3	.5	.4	.7	.6	.8	.6	.8	.8	1.2	1.1	1.3	1.3	1.5	1.4	1.6
	Apr., 1927	.3	.6	.4	.7	.6	.8	.6	.9	.9	1.1	1.1	1.4	1.4	1.5	1.5	1.6
	May, 1927	.2	.4	.4	.7	.5	.7	.5	.8	.9	1.1	1.1	1.3	1.4	1.4	1.5	1.5
	June, 1927	.0	.2	.1	.4	.2	.6	.2	.6	.4	1.0	.6	1.0	1.2	1.3	1.0	1.4
	July, 1927	----	----	.0	.1	.1	.2	.1	.2	.3	.6	.5	.8	.8	1.0	.9	1.0
	Aug., 1927	----	----	----	----	.0	.1	.0	.1	.1	.4	.2	.7	.4	.9	.4	1.0
	Sept., 1927	----	----	----	----	----	----	.0	.0	.0	.2	.1	.2	.1	.3	.2	.4
Liriodendron tulipifera.	Oct., 1926	.1	.2	.2	.3	.3	.4	.3	.6	.4	.6	.7	1.1	1.1	1.6	1.2	1.6
	Nov., 1926	.3	.4	.5	.6	.6	.7	.7	.7	.9	.9	1.3	1.4	1.6	1.6	1.7	1.7
	Dec., 1926	.3	.3	.5	.6	.6	.6	.7	1.0	.8	.9	1.3	1.3	1.6	1.6	1.7	1.7
	Jan., 1927	.3	.4	.5	.6	.7	.8	.8	.8	.9	.9	1.4	1.4	1.6	1.6	1.7	1.7
	Feb., 1927	.3	.4	.6	.7	.8	.8	.8	.8	1.1	1.0	1.5	1.4	1.7	1.6	1.7	1.7
	Mar., 1927	.5	.5	.8	.7	.9	.9	1.0	.9	1.2	1.1	1.6	1.6	1.8	1.7	1.8	1.7
	Apr., 1927	.7	.5	.9	.7	1.1	.8	1.1	.9	1.3	1.1	1.7	1.5	1.8	1.7	1.8	1.8
	May, 1927	.4	.4	.7	.6	.9	.8	.9	.8	1.2	1.0	1.6	1.5	1.8	1.7	1.8	1.7
	June, 1927	.0	.0	.2	.1	.4	.2	.4	.2	.6	.2	1.1	.6	1.4	1.1	1.6	1.2
	July, 1927	----	----	.0	.0	.0	.0	.1	.1	.1	.1	.5	.6	.9	1.0	1.1	1.1
	Aug., 1927	----	----	----	----	.0	.0	.0	.0	.0	.0	.2	.4	.6	.9	.7	1.0
	Sept., 1927	----	----	----	----	----	----	.0	.0	.0	.0	.2	.4	.6	.7	.8	.9
Quercus alba	Oct., 1926	.0	.3	.2	.6	.3	.7	.4	.8	.6	.9	.9	1.1	1.0	1.4	1.1	1.4
	Nov., 1926	.2	.3	.5	.7	.6	1.0	.7	1.0	.9	1.1	1.2	1.4	1.4	1.5	1.4	1.6
	Dec., 1926	.3	.4	.6	.6	.9	.9	.9	.9	1.1	1.1	1.4	1.4	1.5	1.5	1.5	1.5
	Jan., 1927	.4	.6	.6	.8	.8	1.0	1.0	1.1	1.2	1.3	1.5	1.5	1.5	1.6	1.6	1.6
	Feb., 1927	.4	.6	.7	.7	.9	1.0	.9	1.1	1.2	1.2	1.5	1.3	1.7	1.5	1.6	1.6
	Mar., 1927	.5	.7	.8	.9	1.1	1.2	1.2	1.2	1.4	1.4	1.6	1.5	1.6	1.6	1.6	1.6
	Apr., 1927	.7	.7	.9	.9	1.2	1.2	1.2	1.2	1.4	1.4	1.6	1.6	1.7	1.7	1.7	1.7
	May, 1927	.6	.5	.8	.8	1.1	1.1	1.1	1.1	1.3	1.4	1.6	1.6	1.6	1.6	1.7	1.7
	June, 1927	.0	.1	.2	.3	.3	.6	.5	.6	.7	.9	1.1	1.2	1.2	1.4	1.3	1.5
	July, 1927	----	----	.0	.0	.1	.2	.1	.3	.4	.6	.9	1.0	1.2	1.2	1.2	1.3
	Aug., 1927	----	----	----	----	.0	.1	.0	.2	.4	.5	.8	1.0	1.1	1.3	1.2	1.4
	Sept., 1927	----	----	----	----	----	----	.0	.0	.1	.3	.4	.8	.9	1.0	1.0	1.1
Q. borealis maxima	Oct., 1926	.2	.4	.3	.4	.4	.7	.6	.8	.9	1.2	1.4	1.6	1.5	1.8	1.6	1.7
	Nov., 1926	.3	.4	.4	.6	.7	.8	1.0	1.0	1.1	1.3	1.5	1.7	1.5	1.8	1.7	1.8
	Dec., 1926	.4	.5	.6	.9	.6	.9	.9	1.0	1.3	1.4	1.6	1.8	1.8	1.8	1.8	1.8
	Jan., 1927	.4	.6	.8	.8	1.0	1.1	1.1	1.2	1.5	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	Feb., 1927	.5	.6	.6	1.0	1.1	1.2	1.2	1.3	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8
	Mar., 1927	.7	.8	.8	1.0	1.1	1.3	1.1	1.4	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8
	Apr., 1927	.7	.7	.9	1.0	1.2	1.3	1.3	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8
	May, 1927	.5	.6	.8	.7	1.1	1.1	1.2	1.2	1.6	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	June, 1927	.0	.1	.1	.3	.3	.5	.4	.6	.7	.8	1.1	1.2	1.4	1.4	1.5	1.5
	July, 1927	----	----	.0	.0	.0	.1	.1	.2	.5	.8	.8	1.2	1.1	1.6	1.4	1.6
	Aug., 1927	----	----	----	----	.0	.0	.0	.1	.3	.5	.6	1.1	.8	1.3	1.3	1.6
	Sept., 1927	----	----	----	----	----	----	.0	.0	.1	.3	.4	.8	.8	1.1	1.0	1.3
Q. montana	Oct., 1926	.1	.4	.2	.7	3	.7	4	.9	6	1.2	1.1	1.6	1.4	1.8	1.4	1.8
	Nov., 1926	.4	.5	.5	.8	.7	.9	.8	.9	1.1	1.4	1.6	1.6	1.7	1.8	1.8	1.8
	Dec., 1926	.4	.6	.7	.9	.9	1.1	1.0	1.2	1.3	1.5	1.6	1.7	1.8	1.8	1.8	1.8
	Jan., 1927	.5	.7	.7	1.0	1.0	1.2	1.2	1.3	1.5	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	Feb., 1927	.7	.7	1.0	1.1	1.3	1.3	1.4	1.5	1.6	1.6	1.8	1.8	1.8	1.8	1.8	1.8
	Mar., 1927	.8	.9	1.0	1.0	1.3	1.4	1.4	1.4	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8
	Apr., 1927	1.0	.9	1.1	1.2	1.2	1.4	1.3	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8
	May, 1927	.9	.7	1.0	1.0	1.2	1.2	1.3	1.3	1.6	1.6	1.8	1.8	1.8	1.8	1.8	1.8
	June, 1927	.0	.2	.2	.3	.3	.6	.5	.6	.8	1.1	1.2	1.5	1.6	1.7	1.7	1.8
	July, 1927	----	----	.0	.0	.0	.2	.1	.3	.4	.8	.8	1.1	1.4	1.6	1.5	1.7
	Aug., 1927	----	----	----	----	.0	.1	.1	.2	.3	.6	.7	1.2	1.1	1.5	1.3	1.6
	Sept., 1927	----	----	----	----	----	----	.0	.0	.2	.4	.4	1.0	.8	1.3	.9	1.4
Q. velutina	Oct., 1926	.0	.1	.0	.1	.1	.2	.1	.3	.2	.4	.4	.8	.6	.9	.7	1.1
	Nov.. 1926	.1	.2	.2	.4	.5	.6	.6	.8	.7	.9	1.2	1.5	1.6	1.7	1.6	1.7
	Dec., 1926	.2	.3	.4	.4	.5	.6	.7	.8	.8	.9	1.3	1.3	1.6	1.5	1.6	1.6
	Jan., 1927	.2	.4	.5	.6	.7	.8	.8	.9	1.0	1.2	1.4	1.5	1.6	1.7	1.6	1.7
	Feb., 1927	.3	.3	.6	.6	.7	.9	.8	.8	1.1	1.4	1.4	1.6	1.7	1.7	1.7	1.8
	Mar., 1927	.3	.5	.6	.7	.8	1.1	.9	1.1	1.1	1.3	1.5	1.6	1.7	1.7	1.8	1.8
	Apr., 1927	.4	.6	.8	.8	.9	1.1	.9	.9	1.1	1.3	1.4	1.6	1.7	1.5	1.8	1.8
	May, 1927	.2	.4	.5	.6	.8	.9	.9	.8	1.0	1.3	1.6	1.6	1.7	1.8	1.8	1.8
	June, 1927	.0	.2	.1	.4	.2	.6	.3	.7	.6	.9	.9	1.3	1.2	1.6	1.3	1.6
	July, 1927	----	----	.0	.0	.0	.1	.1	.2	.2	.5	.6	.9	.9	1.2	1.1	1.1
	Aug., 1927	----	----	----	----	.0	.0	.0	.1	.1	.2	.4	.7	.7	1.0	.8	1.2
	Sept., 1927	----	----	----	----	----	----	.0	.0	.1	.2	.3	.5	.6	.7	.7	.8

DISCUSSION OF RESULTS

EFFECT OF SEASON OF WOUNDING AS SHOWN BY AREA OF CALLUS

As there are 5,400 measurements included in the diagrams of callus growth, graphs are introduced to facilitate the interpretation of the diagrams and the averaged areas.

Figure 19 is a graphic presentation of the effect which the season of wounding exerted on the amount of callus produced by the healing

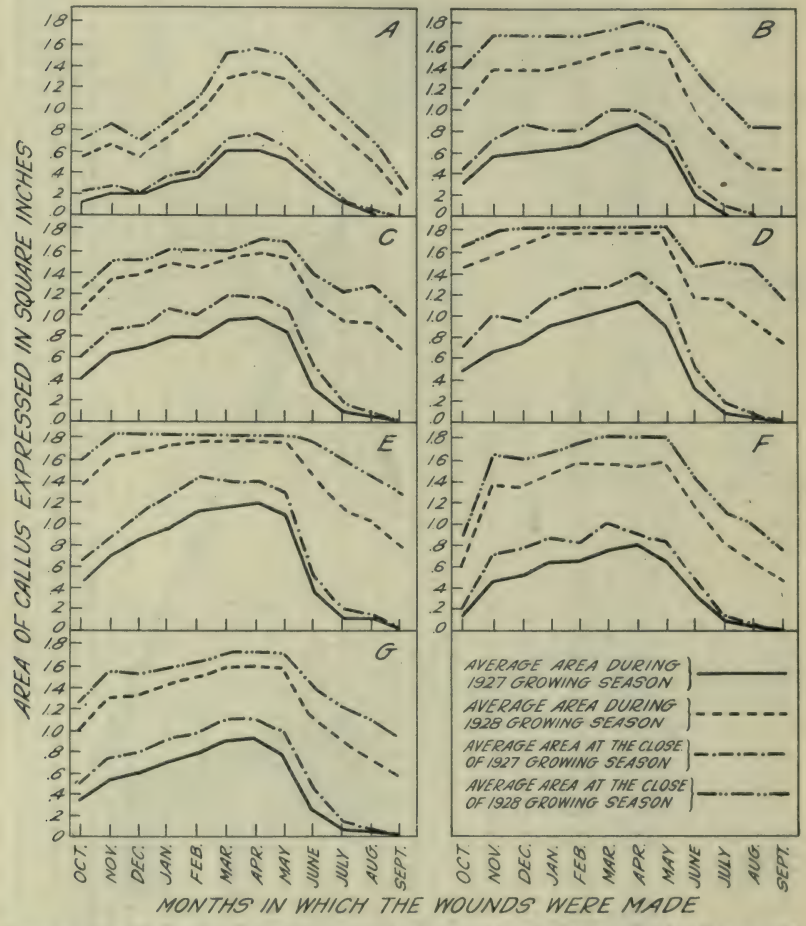

FIGURE 19.—Effect of season of wounding as shown by average area of callus growth produced by the wounds. These averages are for five trees of each species. A, *Acer rubrum;* B, *Liriodendron tulipifera;* C, *Quercus alba;* D, *Q. borealis maxima;* E, *Q. montana;* F, *Q. velutina;* G, average of the six species

of the wounds. (Table 2.) The average areas of callus during the two growing seasons were figured by averaging the areas of the inspections made each season.

In interpreting these graphs it is to be remembered that the area of the completely callused wound is 1.8 square inches. For this reason a flat line must finally be obtained when the wounds have become

completely healed. This feature is illustrated by the upper lines D and E of Figure 19 where the curves have become so much flattened by growth that they fail to peak. Aside from this feature, all four curves in all six graphs (A to F) seem to agree in exhibiting a more or less gradual rise from October to peaking in the period between February and May. In June the curves drop sharply.

From these graphs it is evident that, judged from the area of callus growth, the period from February 15 to May 15 represented, for the trees studied, the most favorable season of wounding. The 15th of the month is specified, since that date was selected as a time of wounding, in preference to the 1st of the month. Should it be desired to shorten still further the season of wounding, February should be omitted, since its results seemed less satisfactory than those of March, April, or May.

EFFECT OF SEASON OF WOUNDING AS SHOWN BY SHAPE OF CALLUS

An attempt has been made to select for each of the 30 trees the three pairs of wounds that show the most satisfactory shape of callus growth. This was judged by their several appearances at the eight examinations. These are tallied in Figure 20, where the large bars (A) represent the result for all 30 trees and the smaller bars (B) the scatter of the curves through the six species of trees studied.

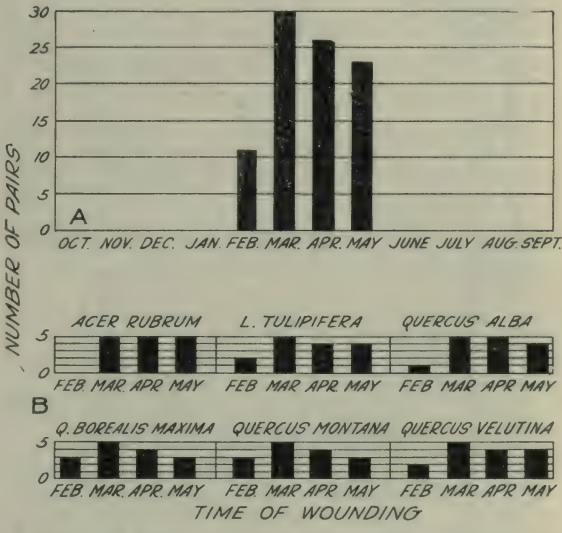

FIGURE 20.—Effect of season of wounding as shown by the shape of callus growth. A, Made by tallying the three pairs of wounds that showed the most satisfactory shape of callus growth; B, scatter of A within the several species

This graph indicates that, judged by the shape of the resulting callus growth, the season between February 15 and May 15 was the most favorable time for wounding the particular tree species studied. Wounds made during February produced somewhat less satisfactory callus than did those made during March, April, or May.

EFFECT OF SHELLAC AS SHOWN BY AREA OF CALLUS

At the time the wounds were made the right-hand wound of each pair was given a single coat of orange shellac. In order to obtain an index of the effect that this dressing exerted upon subsequent healing, the areas of callus produced by the treated and untreated wounds of several pairs may be plotted against each other. Using the average areas given in Table 2, such a plotting may be made by averaging the average figures either down or across the table.

If the figures are averaged downward so as to include an average of all wounds examined at any given inspection, subsequent stages of the closing in of callus growth from no growth toward complete healing are traced. Averaging the wounds made for each month in the year offsets the effect of season. Such a plotting has been made in Figure 21.

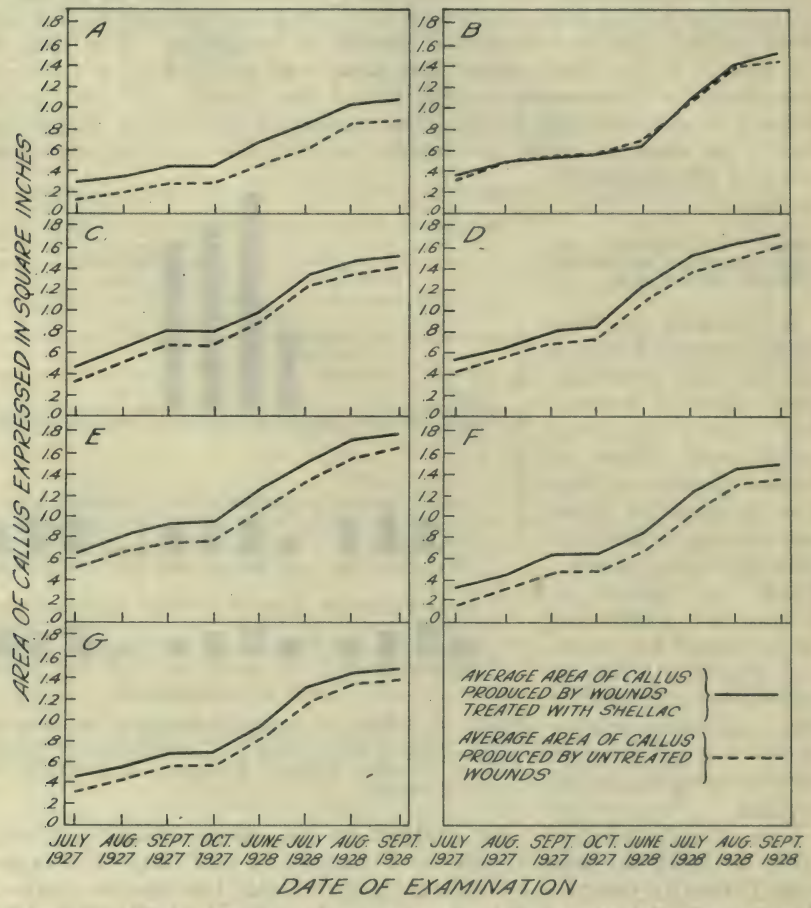

FIGURE 21.—Effect of shellac as shown by area of callus produced. These curves are drawn from averages of five trees of each species. A, *Acer rubrum*; B, *Liriodendron tulipifera*; C, *Quercus alba*; D, *Q. borealis maxima*; E, *Q. montana*; F, *Q. velutina*; G, average of the six species

Examination of the curves shows that they follow each other closely and are practically parallel. No continuous effect is demonstrated in the application of shellac as a wound dressing, since these lines of average growth are neither divergent nor convergent. The effect of the treatment has been immediate, the initial rate of healing having been stimulated. This effect has been carried over into subsequent examinations without becoming evidently greater or less.

In five of the six species of trees the use of shellac as a wound dressing is indicated to be of value, as evidenced by the fact that

the curve of the average growth of wounds to which shellac was applied is above the curve of the untreated wounds. In one case, that of *Liriodendron tulipifera*, there is no evidence that the use of shellac hastened the healing of the wounds. Here the average curves are not only nearly parallel, but they are practically coincident.

The writer is unable to explain definitely why shellac should have proved beneficial as a wound dressing for five species of trees and of no value to a sixth, although there was one feature of difference in the wounds of this tree compared with those of the other species. For the most part the wounds of *Liriodendron tulipifera* showed a slime-flux condition. This trouble was not observed in any wound of any of the other species under experiment. The slime flux formed a more or less profuse, thick, black ooze which ran down the trunk. (Figs. 22 and 23.) Neither its chemical nature nor its flora was investigated. Slime flux appeared to be equally severe on both shellacked and untreated wounds, and for this reason it could not of itself account for the failure of the treatment. The cause of the slime flux may, however, furnish a possible explanation of the difference in reaction of this species and that of the five species in which the trouble was not observed. Slime flux probably developed primarily because of a continued flow of sap from the wounds of the tree. If, as is generally supposed, the value of shellac as a wound dressing lies in its protection of the otherwise exposed growing layer from drying, it seems possible that a continual flow of sap from the wound might also prevent the drying out of the exposed cambium tissue and so effect the benefit otherwise to be derived from the application of shellac.

FIGURE 22.—Yellow poplar showing flow of slime flux as thick black ooze from most of the wounds

In order to show the relative effect obtained by applying shellac at various seasons, the average areas of callus growth have been averaged across the chart for each of the two seasons as in Figure

19, with the exception that the check and shellac wounds have been plotted against each other rather than together. The resulting curves, given in Figure 24, show that in general the application of shellac is least beneficial when applied to wounds made in the spring. The seasonal variation of benefit derived from shellac is slight in *Quercus velutina* and in *Acer rubrum*. The seasonal effect is most marked in the case of *Liriodendron tulipifera*. Here the curves cross markedly, showing that the application of shellac stimulated callus formation when applied to wounds made between July and January, but retarded callus formation when applied to wounds made between February and June.

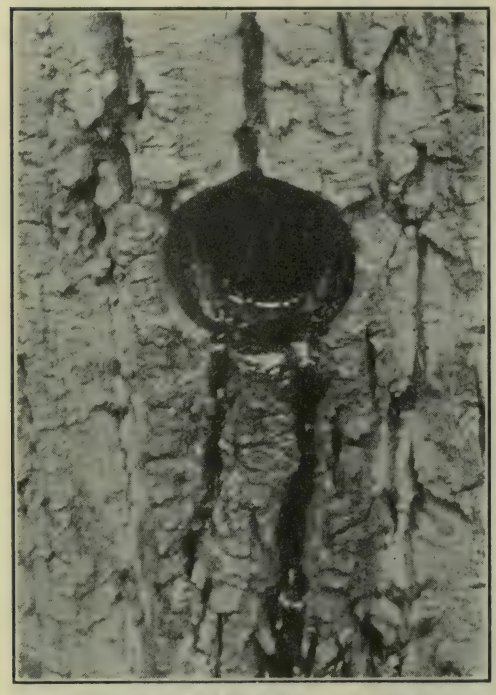

FIGURE 23.—Close view of one of the wounds shown in Figure 22

EFFECT OF SHELLAC AS SHOWN BY SHAPE OF CALLUS

To determine whether the application of shellac exerted a favorable influence on the shape of the callus ultimately produced, the results in the diagrams of callus growth were tallied. Looking across the sheet, the appearances of series of paired wounds were considered for the entire period of two seasons. An attempt was made to determine whether the check wound or the shellacked wound of each pair presented the more desirable outline of healing during these two years. If the callus produced by the check wound seemed the more favorable, it received a tally. If the shellacked wound were the better, it was tallied. If the healing was approximately of equal desirability, neither check nor shellac was tallied.

The results of the tally are assembled in Table 3. Since five trees of each species were included, the individual number combinations shown in the body of the table are based upon 5 cases, the totals at the bottom of the table upon 60 cases, and the totals at the right upon 30 cases.

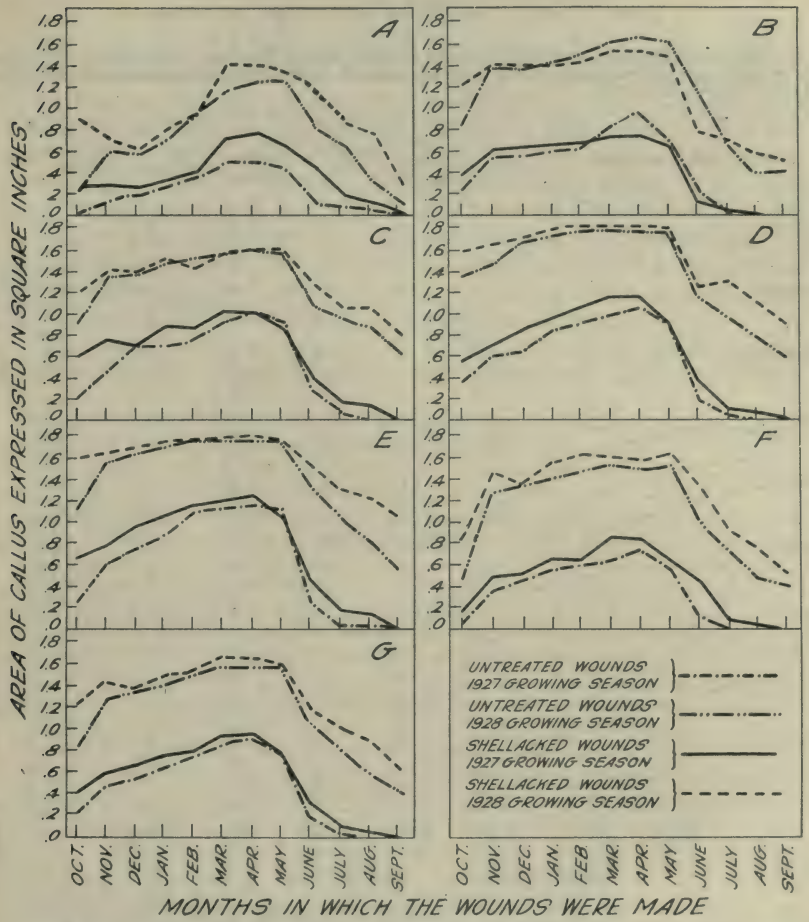

FIGURE 24.—Relative effect of applying shellac at various seasons as shown by the average area of callus for the growing season. These curves are drawn from averages of five trees for each species. A, *Acer rubrum;* B, *Liriodendron tulipifera;* C, *Quercus alba;* D, *Q. borealis maxima;* E, *Q. montana;* F, *Q. velutina;* G, average of the six species

TABLE 3.—*Effect of shellac upon shape of callus*

[In this table the shellacked and untreated wounds of paired wounds have been tallied against each other the better wound receiving a tally. The tallies of shellacked wounds are above the dashes and the tallies of the untreated are below]

Month wound was made	Acer rubrum	Liriodendron tulipifera	Quercus alba	Q. borealis maxima	Q. montana	Q. velutina	Total
October	5	3	4	4	5	2	23
	0	0	0	0	0	1	1
November	4	1	4	3	3	2	17
	1	1	0	0	0	0	2
December	3	2	0	2	3	1	11
	0	1	1	0	0	1	3
January	2	1	1	2	2	1	9
	0	1	0	0	0	0	1
February	1	1	1	1	2	3	9
	2	2	0	0	1	0	5
March	4	1	1	4	2	2	14
	1	3	1	0	1	0	6
April	3	0	0	2	4	1	10
	0	5	0	0	0	0	5
May	2	0	1	2	1	3	9
	1	4	2	2	3	0	12
June	5	1	3	2	3	5	19
	0	4	0	1	0	0	5
July	3	3	3	4	4	3	20
	0	2	1	0	0	1	4
August	4	2	4	5	4	4	23
	0	1	0	0	1	0	2
September	4	3	4	4	5	2	22
	1	0	0	0	0	0	1
Total	40	18	26	35	38	29	186
	6	24	5	3	6	3	47

An examination of the row of totals in the lower line of the table shows that there is no significant difference between the shellacked wounds and the check wounds of *Liriodendron tulipifera*. If minor differences are sought, they are against rather than in favor of treatment. In the case of the five other species of trees the differences are significant in favor of the shellac.

Examining the totals to the right in order to determine the effect of the applications of shellac during the several months, it is noted that the figures are not significant for the month of May and that they become increasingly significant in favor of the shellac as the months of September and October are approached.

EFFECT OF VIGOR ON HEALING

The vigor of the tree wounded has always been recognized as of prime importance to callus formation. The effect of this factor was best illustrated in the present experiment in the case of *Quercus alba*, where the unusual ability of the species to heal rapidly was felt to warrant the inclusion of individuals lacking vigor. In fact, the poorest tree used in the experiment was barely alive. The average areas of callus growth of the first four trees of this species are plotted in Figure 25. The fifth tree was not plotted because both its vigor and its growth curve were practically identical with that of tree No. 3. The relative vigor of the trees was judged by averaging the growth of 10 seasons, 1917 to 1926, from increment borings.

The areas of callus growth of all wounds, both treated and untreated, have here been averaged for each of the eight examinations.

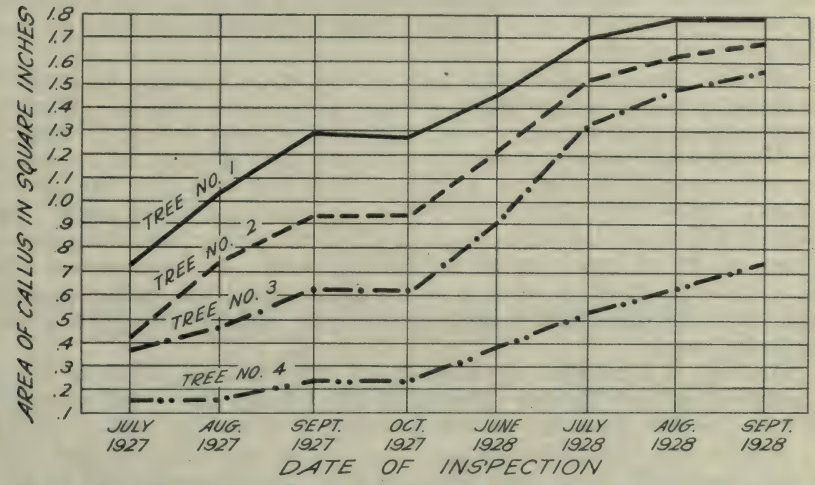

FIGURE 25.—Effect of vigor on healing as shown by the area of callus growth produced by four trees of *Quercus alba*. Average yearly diameter growth: Tree No. 1, 0.15 inch—vigorous tree; No. 2, 0.12 inch—fairly vigorous tree; No. 3, 0.10 inch—weak tree; No. 4, 0.06 inch—very weak tree

The resulting curves of average growth registered for the successive examinations differ markedly. So great is the effect of vigor that the most vigorous tree is seen to have formed as much average callus growth at the first examination of the first growing season as had the poorest tree at the time of the last examination of the second growing season. The effect of the relative vigor of the four individuals is best illustrated by their growth during the first year, for in the second year curves converge toward 1.8 square-inch line as the callusing over of the wounds becomes complete.

FUNGUS GROWTH ON THE WOUNDS

Aside from the usual occurrence of the lower forms of fungi, the most evident of which were various sap-stain organisms, a single form of basidiomycete was observed fruiting on the experimental wounds. This fungus was *Panus stipticus* Fr. The sporophores

were well formed though small because of their crowded condition in the wounds. Only two wounds showed these mature fruiting structures. In both cases they were first observed at the September, 1928, examination on *Quercus borealis maxima* Nos. 3 and 4 in the check wounds made in August, 1927. Since the sapwood about these wounds was sound, the organism had presumably infected through the auger holes.

APPLICATION OF RESULTS

The results of the experiment indicate that callus development of wounds made between February 15 and May 15 was, in the case of the species studied, better both in the shape that it assumed and in the area that it covered, than was that of wounds made at any other period. It is then probable that pruning and cavity work that can be conducted in the spring of the year will have advantage in callus production over similar work performed during the summer, fall, or winter.

On the other hand, it may not always be practicable to perform a major part of the pruning during the spring season. Weather conditions are not especially favorable for pruning during February; in March high winds frequently increase the difficulty of operating on tall trees; while during April and May the task of spraying frequently causes any but the most pressing duties to be set aside. But even in this event the advantageous effect of spring wounding should prove to be of much value in dealing with (1) tree species that have delicate bark or that tend to form but little callus growth, (2) the individual that is lacking in vigor, and (3) the particularly valuable tree.

Possibly a principal application of this seasonal effect is to the treatment of such fungus diseases as affect twigs and small branches. While the life histories of the particular forms for which control is sought are highly important, it is to be remembered that some fungi, especially those that belong to the Ascomycetes, tend to fruit very early in the season. Theoretically, thorough pruning in February would therefore seem to be advantageous from a number of angles:

(1) It should remove the diseased parts before the fruiting of the causal pathogene and so lessen the spread of infection.

(2) Pruning at this season would permit the use of reasonably strong fungicides as dormant sprays immediately following the removal of the diseased wood.

(3) It is impossible to apply wound dressing to the numerous small cuts resulting from twig pruning, and yet the same spray which affords temporary protection against the infection of other parts must also afford temporary protection to such cuts. This is a point which the orchardist has long recognized but which the commercial tree expert has often overlooked.

(4) Such a season of pruning would be in accord both with discussed favorable season of wounding from the standpoint of callus formation and with the time determined by Swarbrick (*15*) as most favorable to rapid blocking of the wood vessels with wound gum and the consequent formation of barrier against infection through the cut surface ultimately left exposed by the weathering of the protecting cover of spray material.

Although the use of shellac as a wound dressing failed to give results with the yellow poplar, its effect was favorable with the re-

maining five species. It therefore seems probable that, in general, such an application may be of considerable value in temporarily protecting the otherwise exposed cambium tissue. For this reason it is recommended, where practicable, that all cut surfaces of the cambium be given an immediate application of some protective dressing that is known to be noninjurious to this tissue. If shellac or any similar product is used for this purpose it is not to be interpreted from the present investigation as of value for the protection or preservation of the wound itself against weather, insect, or decay. This substance has been tested merely for its effect on the growth of the callus.

Vigor is a prime factor in healing. When a tree is to receive cavity work or considerable pruning, particularly that which involves the removal of large branches, its general vigor should be carefully considered. If it is in a condition of low vigor, the rectification of any known unfavorable condition may be of great advantage in aiding the rapid healing of the cuts. Such unfavorable conditions may arise from numerous causes, common among which are lack of sufficient soil moisture at some time during the year, insufficient drainage, the exhaustion of the available forms of certain chemical elements in the soil which are important to plant growth, improper mechanical condition of the soil, lack of soil aeration, the presence of toxic substance in the soil or air, and the presence of fungus or insect pests.

SUMMARY

Five trees each of *Acer rubrum*, *Liriodendron tulipifera*, *Quercus alba*, *Q. borealis maxima*, *Q. montana*, and *Q. velutina* were wounded by boring holes with a 1½-inch auger. One pair of wounds was made on each of the 30 trees on the 15th day of each month during the course of a year. One wound of each pair was shellacked; the other was left untreated.

Developments were followed through two growing seasons. Diagrams of the growth of callus in these wounds were drawn on the 15th day of the month. At the end of this period there were 5,400 individual diagrams representing the appearance of the callus growth at the several inspections.

Wounds made between February 15 and May 15 developed callus growth of more desirable shape and greater area in all six species of trees than did wounds made at any other time.

A single coat of orange shellac applied immediately following wounding was an aid to callus formation in five of the species. In the sixth (*Liriodendron tulipifera*) its application had no appreciable effect. Where the application of shellac was beneficial the result of its use was evident at the first examination. This advantage carried over into subsequent examinations without becoming appreciably greater or less. The effect of shellac on the formation of callus may vary with the season at which the shellac is applied.

The vigor of the individual tree was found to be of prime importance to healing, callus formation being much more rapid in vigorous trees than in weak trees.

LITERATURE CITED

(1) BAILEY, L. H.
1914–17. THE STANDARD CYCLOPEDIA OF HORTICULTURE . . . 6 v., illus. New York.

(2) BEDFORD, DUKE OF, and PICKERING, S. U.
1905. EXPERIMENTS ON PRUNING. Woburn Expt. Fruit Farm Rpt. 5: 21–40.

(3) BRIERLY, W. G.
1925. APPLE PRUNING INVESTIGATIONS. I. COMPARISON OF FALL, WINTER, AND SPRING PRUNING. II. RENOVATION. III. WOUND HEALING. Minn. Agr. Expt. Sta. Bul. 225, 22 p., illus.

(4) CHANDLER, W. H.
1923. RESULTS OF SOME EXPERIMENTS IN PRUNING FRUIT TREES. N. Y. Cornell Agr. Expt. Sta. Bul. 415, 75 p., illus.

(5) COLLINS, J. F.
1922. TREE SURGERY. U. S. Dept. Agr. Farmers' Bul. 1178, 32 p., illus. (Revised.)

(6) CORBETT, L. C.
1903. PRUNING. U. S. Dept. Agr. Farmers' Bul. 181, 40 p., illus.

(7) DURAND, L.
1853. THE APPLE ORCHARDS. Hort. and Jour. Rural Art and Rural Taste (n. s. 3) 8: 369–371.

(8) HOWE, G. H.
1915. EFFECT OF VARIOUS DRESSINGS ON PRUNING WOUNDS OF FRUIT TREES. N. Y. State Agr. Expt. Sta. Bul. 396, p. [83]–94.

(9) LINDLEY, J.
1841. THE THEORY OF HORTICULTURE: OR AN ATTEMPT TO EXPLAIN THE PRINCIPAL OPERATIONS OF GARDENING UPON PHYSIOLOGICAL PRINCIPLES. Amer. Ed. 1, with notes by A. J. Downing, 346 p., illus. New York.

(10) LONG, E. A.
1896. SUGGESTIONS ON TREE PRUNING. Amer. Gard. 17: 180–181, illus.

(11) PEETS, E.
[1925.] PRACTICAL TREE REPAIR; THE PHYSICAL REPAIR OF TREES. BRACING AND TREATMENT OF WOUNDS AND CAVITIES. Rev. ed., 270 p., illus. New York.

(12) PRIESTLEY, J. H.
1926. THE NATURAL HEALING OF WOUNDS ON TREES. Jour. Min. Agr. [Gt. Brit.] 33: 248–254.

(13) ROSE, D. H.
1917. EFFECT OF VARIOUS DRESSINGS ON PRUNING WOUNDS OF APPLE TREES. Missouri State Fruit Expt. Sta. Circ. 10, [4] p.

(14) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES—THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 295 p.

(15) SWARBRICK, T.
1926–27. THE HEALING OF WOUNDS IN WOODY STEMS. Jour. Pomol. and Hort. Sci. 5: 98–114, illus., 1926; 6: 29–46, illus., 1927.

(16) WILTSHIRE, S. P.
1923. WOUND DRESSINGS. Jour. Bath and West and South. Counties Soc. (5) 17: 189–190.

(17) ZEDERBAUER, E.
1909. UNTERSUCHUNGEN ÜBER DIE AUFASTUNG DER WALDBÄUME. Centbl. Gesam. Forstw. 35: [413]–427, illus.

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29

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TECHNICAL BULLETIN No. 247 AUGUST, 1931

FOREST TYPES IN THE SOUTHWEST AS DETERMINED BY CLIMATE AND SOIL

BY

G. A. PEARSON

Director, Southwestern Forest and Range Experiment Station
Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page
Introduction	1
The forest types or zones and other vegetational zones of Arizona and New Mexico	3
Woodland	5
Western yellow pine zone	7
Douglas fir zone	9
Engelmann spruce zone	12
Climate	15
Sources of data	15
The growing season	19
Temperatures	21
Precipitation	48
Wind, humidity, and evaporation	58
Soil moisture	63
Soils	72
Geologic origin	72
Chemical composition	73
Physical characteristics	75
Soil zones as related to climate	80
Description of the soil zones	82
Résumé of findings on climate and soil	85
Characteristics of the species	86
Relative heat requirements	86
Relative light requirements	89
Relative moisture requirements	93
Growth periods	99
Frequency of seed crops	100
Rate of growth	101
Correlation between physical conditions and the distribution of species	105
Planting experiments	105
Natural occurrence an indication of requirements	114
Temperature and moisture as limiting factors in natural distribution	115
Range of temperature and moisture within each forest zone in the Southwest	119
Specific requirements of species	123
Temperature and moisture requirements	123
Soil requirements	125
Application of data on forest types to forestry practice	125
Need for further study	125
Measurement of site factors	126
Possibilities in the use of plant indicators	127
A scientific basis for silviculture	128
Summary	131
Appendix	134
Methods of study employed in compiling the San Francisco Mountains records	134
Description of climatological stations employed in the San Francisco Mountains study	137
Literature cited	141

INTRODUCTION

No other form of agriculture is so completely subject to the forces of nature as is the growing of timber crops. Trees may not be more sensitive to changes in their environment than are other forms of vegetation, but their long span of life calls for greater constancy of favorable conditions than is required by plants which mature and reproduce in one or a few years. In only a very limited way is it possible for man to modify these forces, and therefore the forester, to be successful, must understand and learn to work in harmony with them.

[1] The Southwestern Forest and Range Experiment Station is maintained in cooperation with the University of Arizona. The investigation here reported has been confined almost entirely to Arizona and New Mexico. Although these two States do not comprise the entire region generally included in the more or less vaguely defined Southwest, they do constitute the major and most typical part as far as the forestry is concerned.

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The observation that certain tree species and types of forest are associated with certain types of climate and soil is older than forestry itself, for long before forestry was practiced biologists had learned to recognize forest trees as indicators of climatic zones. As for the forester, nothing could be a more quickening challenge to his research instinct than the question of why one tree species makes its home on the mountain tops, another in the valleys, and another on intermediate slopes. Such questions were among the first to engage the attention of research workers at Forest Service experiment stations. Studies of climatic zones in relation to the natural occurrence of forests have been made by Bates (*2*)[2] in Colorado, and by other workers[3] in Idaho, Montana, Utah, and California; also by the writer (*32*) in Arizona as a preliminary to the present bulletin. Among other contributions in the same general field but dealing less specifically with forest trees are the works of Merriam (*29*), Clements (*12*, *13*), Clements and Weaver (*14*), Sampson (*38*), Shreve (*41*), and Livingston and Shreve (*26*).

Although progress has been made in the correlation of vegetation and physical conditions, much remains to be done. Forest meteorology in this country is still in its infancy. Soil surveys such as are made in agricultural sections are not adapted to forest lands. Furthermore, even if soil and meteorological data were available, neither foresters nor other plant investigators are in a position to know how to apply them effectively. Our knowledge concerning the reactions of plants to changes in heat, light, and moisture is inadequate. Too little distinction is made between air temperature and plant temperature and between air temperature and insolation. "Light" in the forest may be more a phenomenon of heat than of illumination. Moisture effects are more readily perceived than are those of heat and light, but under natural conditions the three are so intimately related that confusion is avoided with difficulty. Properly conducted experiments would do much to clarify our conceptions of these important subjects.

The object of this investigation has been further advancement toward an understanding of the biological relations between forests and their environment. More specifically, the object has been to ascertain under what conditions different kinds of forests do or do not occur, and in this way obtain an expression of their requirements. In such a study, the first step is to obtain a measure of the physical conditions prevailing in each type of forest. If it is found, as has in fact proved to be the case, that a given forest association represents rather definite conditions of climate and soil, a knowledge of these relationships is of obvious value. Having this in mind, the writer has presented the available records of physical factors with a view to serving forest management and future research as well as the immediate purpose of this investigation. The correlation between forests and physical conditions should not only designate the critical factors but also express them in quantitative terms. It should go a step further and state the range of optimum and possible conditions for each species. The present investigation has not been carried far enough to treat this phase in a final manner, but such available figures as seem justified will be presented.

[2] Italic figures in parentheses refer to Literature Cited, p. 141.
[3] The results of these studies are not yet published.

Although soil as a factor in the demarcation of forest types probably deserves more attention than it has received, it is in this region overshadowed by climate. Besides exerting greater direct influences upon vegetation, climate, as will be shown later, determines to a large extent the character of the soil.[4]

THE FOREST TYPES[5] OR ZONES AND OTHER VEGETATIONAL ZONES OF ARIZONA AND NEW MEXICO

Altitude far more than latitude determines the character of climate and vegetation in the Southwest. Altitudes range from less than 100 feet in southwestern Arizona to about 13,000 feet in northern Arizona and northern New Mexico. Forests occur mainly above the 5,000-foot contour, the lower limit depending somewhat

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FIGURE 1.—Luxuriant growth of grama grass (*Bouteloua rothrockii*) on a protected area in the so-called desert of southern Arizona. Mesquite bushes (*Prosopis velutina*) in the background

upon exposure, soil, and other local conditions. The upper limit of tree growth approximates 11,500 feet, varying with local conditions, of which exposure is the most important.

[4] It is of interest to note that in a similar investigation by Cajander (*8*) in Finland, soil is regarded as the all-important factor, climate being barely mentioned. This difference may be accounted for by the fact that in Finland local climatic variations are so small as to be inconsiderable.

[5] The term "forest type," as generally understood by foresters, denotes an ecological unit characterized by uniformity in composition as to tree species. Corresponding uniformity in physical conditions is usually implied. Forest types are as a rule designated by the names of the species which predominate in the stand as, for example, western yellow pine type or Douglas fir type. Among ecologists the terms "association" or "consociation" are synonymous with forest type, consociation being restricted to units which are dominated by a single species. Thus, the western yellow pine type would be called a consociation, whereas the Douglas fir type, which usually is made up of several species, or the mixed-conifer type, would be called an association. Plant succession is recognized by the forestry profession in the use of the terms "temporary" and "permanent" forest type. "Forest influences," meaning the reaction of the trees and other vegetation upon soil, water, and atmospheric conditions, appears in the oldest forestry literature.

Four forest zones or types are commonly recognized in this region. These are, in ascending order, the woodland, western yellow pine,[6] Douglas fir, and Engelmann spruce. Below these are two non-

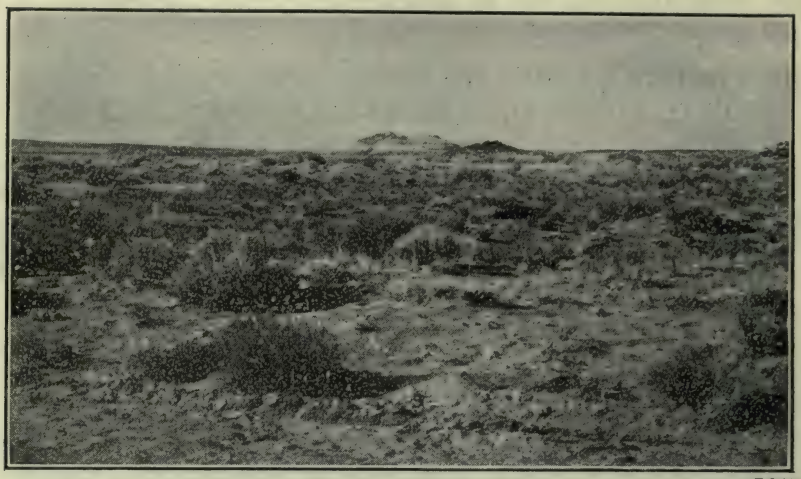

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FIGURE 2.—A common shrub-grass association of the grassland formation. *Chrysothamnus* sp., *Atriplex* sp., *Gutierrezia sarothræ*, *Bouteloua gracilis*, *B. curtipendula*, and *Sporobolus airoides*. The grasses and the Atriplex have been closely grazed

forest zones which, while they are not treated in this bulletin in any detail, are sketched in roughly to complete the regional picture of plant zones. Thus, lowest of all lies what is popularly known

F-205400

FIGURE 3.—Transition from grassland to woodland east of Flagstaff, Ariz. Altitude about 5,700 feet; grassland vegetation with a few dwarf specimens of one-seed juniper. The precipitation here is slightly more than 9 inches, and the soil is moderately shallow. The lower border of the woodland may be seen as a dark line in the distance

as the desert (fig. 1), in reality a zone very rich in plant life. Shrubs now prevail in the desert zone, although grasses were

[6] The name *Pinus scopulorum* has been applied to the Rocky Mountain form of western yellow pine occurring in this region in order to distinguish it from the more or less distinct Pacific coast form. The Forest Service, however, has officially adopted the name *P. ponderosa* for both forms, and this name will be used throughout the present bulletin.

probably abundant before the days of intensive grazing. Above the desert is the grassland zone (fig. 2), which, with the not always distinctive chaparral zone, merges into the lower margins of the woodland (fig. 3). The distinction between grassland and desert is rather arbitrary but is based upon a recognition of the obviously greater dryness prevailing below an altitude of about 3,000 feet.

The plant zones here discussed have been taken up in their natural

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FIGURE 4.—A, *Juniperus utahensis* encroaching upon open areas. In the region south of Ash Fork, Ariz., thousands of acres of what is apparently grassland but probably in reality is burned woodland are being invaded by juniper. B, Typical piñon-juniper woodland

vertical order, indicating the approximate altitudinal limits and characteristic species of each. A general description of the woodland and timberland zones follows.

WOODLAND

Foresters use the term " woodland " to distinguish the low, spreading tree growth characteristic of this lowest of the several zones

occupied by continuous bodies of trees. Two or more fairly distinct kinds of woodland, each of which may be designated as a forest type, occur in the Southwest. Of these the piñon-juniper type is most common. It is made up of several species of piñon and juniper and is rather common over the entire region between altitudinal limits of 5,000 and 7,000 feet. The evergreen-oak type, represented mainly in Arizona oak and Emory oak, is confined to the southern half of the region between altitudes of about 4,500 and 6,000 feet. Stands of Arizona cypress (*Cupressus arizonica*) and smooth cypress (*C. glabra*) in southern Arizona might also claim recognition as forest types, although they are of too little extent to be of much commercial importance.

The usually open character of the woodlands, often caused by fire, permits abundant growth of herbs and shrubs between the trees. (Fig. 4, B.) The most characteristic grass is blue grama (*Bouteloua gracilis*). Species of the grassland formation, such as side-oats grama and tobosa grass, are also more or less common. Characteristic shrubs in the piñon-juniper type are quinine bush (*Cowania mexicana*) and mountain-mahogany (*Cercocarpus montanus*). Sagebrush (*Artemisia tridentata*) is the predominant shrub within this type over large areas in northern Arizona and northern New Mexico.

Mainly because the piñon and the two most common junipers, one-seed and Utah, are very sensitive to fire, large areas of woodland have been almost completely wiped out by this agency, probably in conjunction with bark beetles. Such areas may become grasslands, or, where overgrazing has followed fire, they may grow up to brush, as suggested by Leopold (*25*). It is doubtful, however, whether typical chaparral originates in this way, because it shows many indications of being a climax formation. This view has been expressed by Calkins (*9*). If fires are kept out of woodland burns, the trees come back in time, especially within the range of Utah juniper, which is particularly aggressive as an invader of new territory. (Fig. 4, A.) Investigations by Miller (*30*) have shown that sheep, feeding on the berries, are an important agency in disseminating this juniper. Moreover, the junipers, unlike the pines, firs, and spruces, are seldom browsed. Since the seeds of all these trees are heavy, most of them fall directly under the outer edge of the crown where the seed bed is best. Here decayed leaf litter has formed a mulch on the surface of the soil, and the shade, while preventing excessive evaporation is not sufficient to suppress the seedlings. It is common for piñon and juniper seedlings to spring up in large numbers close around the old trees.

Although the woodlands produce but little saw timber and generally give good yields of farm crops only under irrigation, they are of considerable economic importance, particularly as this type clothes extensive watershed areas. They afford excellent grazing and nearly all of the tree species present are valuable for fuel. The junipers are highly prized for fence posts. In northern New Mexico the piñon is very largely used for ties and props in coal-mining operations, and in recent years the piñon-nut industry has assumed economic importance. Because in this zone the biological balance is very delicately adjusted, excessive grazing, clearing of lands, cutting, and fire, coupled with fairly heavy storms, have perhaps a greater effect than in any of the other zones in causing serious erosion.

WESTERN YELLOW PINE ZONE

Western yellow pine occurs in pure stands at altitudes ranging most commonly from 7,000 to 8,000 feet. The Arizona pine of southern Arizona is similar in appearance but is distinguishable by the fact that it has from three to five needles in a sheath whereas western yellow pine usually has only two or three. Still another species of very limited occurrence in southern Arizona is Apache pine (*Pinus apacheca*). Toward the lower limits of the type, piñon and one or more of the junipers occur in mixture with western yellow pine; toward the upper limits limber pine, Douglas fir, and white fir are common associates. Rocky Mountain white oak (*Quercus utahensis*), a distinctly subordinate species, grows with western yellow pine through a considerable portion of its range.

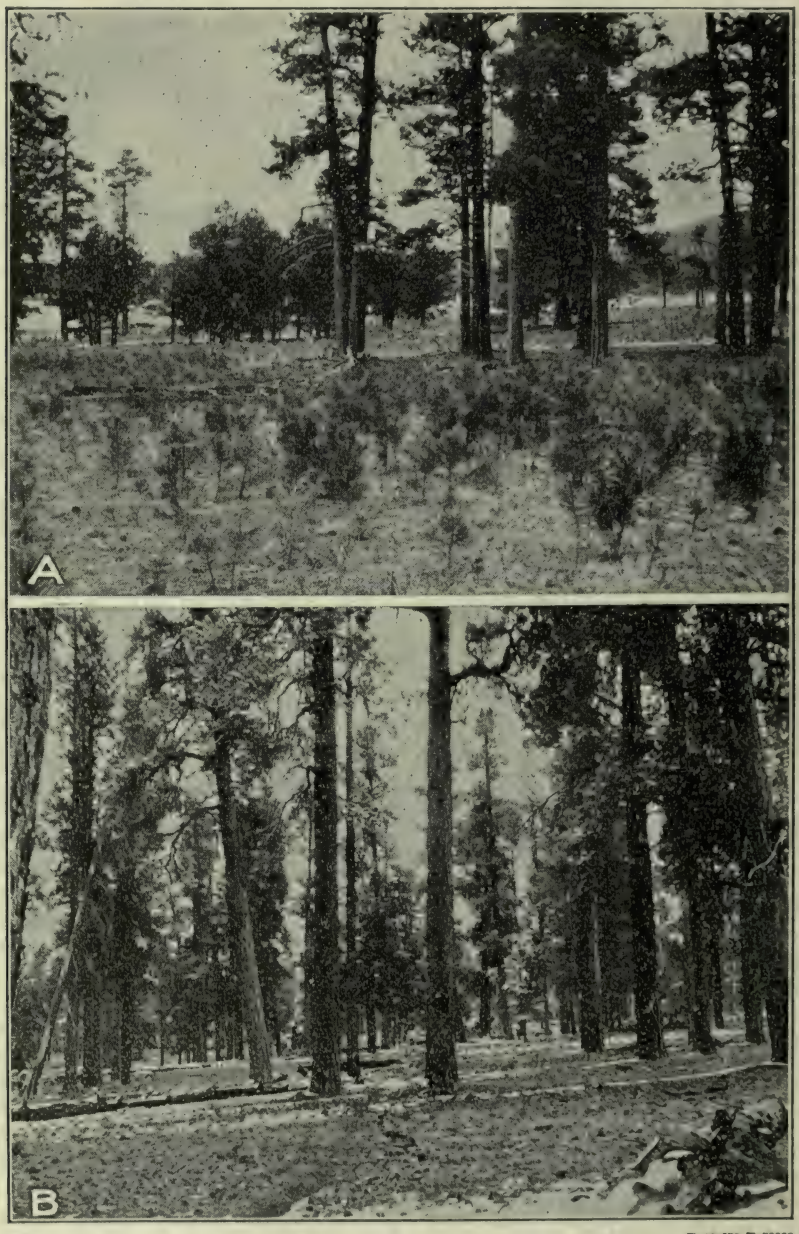
Like the woodlands, the western yellow pine forest, because of recurring fires which have killed the young growth from time to time, is open, permitting a great variety of herbs and shrubs to grow between the trees. Characteristic grasses are the bunch grasses (*Festuca arizonica*, *Muhlenbergia montana*, and *Blepharoneuron tricholepis*), squirreltail grass (Sitanion), wheatgrass (*Agropyron smithii*), black dropseed (*Sporobolus interruptus*), and June grass (*Koeleria cristata*). Blue grama is common in parks and in the lower edges of the western yellow pine zone, but it is not characteristic on optimum western yellow pine sites. Among the more common nongrasslike herbs are yarrow (*Achillea lanulosa*), the lupines, of which there are several species, meadow rue (*Thalictrum wrightii*), red and yellow pea (*Lotus wrightii*), vetch (*Vicia americana*), sage (*Artemisia dracunculoides* and *A. mexicana*), and loco weeds (Oxytropis), *Senecio spartioides*, and pingue (*Actinea richardsoni*). The scrub oaks (*Quercus gambelii*, *Q. undulata*, and *Q. reticulata*), mountain-mahogany, and cliffrose or quinine bush are common in the lower edge of the type.

An outstanding feature of the western yellow pine forests is the tendency of the trees to occur in even-aged groups. Within a radius of 100 feet one may find groups of veteran western yellow pines, of immature "blackjacks," of poles 6 to 8 inches in diameter, and of seedlings or saplings. (Fig. 5.) Groups above the sapling size vary from 3 or 4 trees to as many as 50. In some localities the grouping habit is less pronounced than in others, but it is everywhere noticeable. Mature trees are from 200 to 400 years old, and one specimen was found to be 640 years old, but merchantable size is attained in from 150 to 200 years. Maximum diameters are 4 to 5 feet, and heights range up to 125 feet. (Fig. 5, B.) The number of trees more than 12 inches d. b. h.[7] per acre in a virgin stand ranges from 15 to as high as 50. The volume per acre usually runs from 8,000 to 10,000 board feet, although in certain localities, notably the Sitgreaves National Forest of Arizona, yields as high as 20,000 board feet are common. It is believed that under protection against fire and grazing damage, stands of the heaviest type now found would be the rule rather than the exception.

Because of their high timber value and their accessibility, the western yellow pine forests have been heavily exploited. Unregu-

[7] D. b. h. = diameter at breast height (4.5 feet).

lated cutting followed by fire and overgrazing has resulted in nearly complete denudation of many areas. Where seed trees are left



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FIGGURE 5.—Typical stands of western yellow pine; A, open stand with seedlings and saplings between groups of old trees; B, dense mature stand

and young growth is protected, a perpetual stand is usually assured. Fire does not as a rule destroy mature trees unless fed by a large amount of dry material, such as slash left after cutting. Ordinary

grass fires, however, destroy seedlings and saplings and result in a thinning of the mature stand by killing some of the large trees.

With the development of the forest as a timber-producing area goes its conservation as a watershed and recreational area. Although the western yellow pine stands are not dense enough to form an ideal watershed, the tree canopy, together with the leaf litter, the young tree growth, and the herbaceous vegetation, exerts an important influence in regulating run-off and checking erosion.

A considerable acreage of open or sparsely timbered land within the western yellow pine zone has been brought under cultivation. Under the most favorable conditions, good crops can be grown without irrigation. Except in favored locations, however, the climate is too cold for anything but hardy cereal and root crops. What with the short seasons and droughts, crop failures are common. As a rule only parks [8] are suited for farming. Most forest lands are too rocky or too rough for successful cultivation, and even

F-43870A

FIGURE 6.—Clear cutting and fire in western yellow pine forests result in devastation. Centuries will be required to build up such areas to their full forest productivity

where soil and topography are favorable the expense of removing stumps is seldom warranted. (Fig. 6.)

Grazing is an important local industry in this type. Unfortunately it has been conducted in a manner highly detrimental to timber, water, and land resources. On thousands of acres stands of young pine seedlings have been destroyed or decimated. Where continued overgrazing has killed out much of the herbaceous cover, this, together with trampling, has resulted in erosion on a large scale.

DOUGLAS FIR ZONE

Although Douglas fir is generally regarded as the characteristic tree of this type (fig. 7), yet, unlike western yellow pine, it rarely occurs in pure stands in this region. Common associates are white fir, which often predominates on north slopes, limber pine or Mexican white pine (*Pinus strobiformis*), and blue spruce (*Picea pungens*). In the lower portion of the type western yellow pine and in the upper portion Engelmann spruce occur in mixture. Aspen is common throughout and extends well into the Engelmann

[8] The word "park" is applied locally to treeless areas within a forest.

spruce type above. (Fig. 8.) In old, well-stocked stands of conifers aspen almost disappears, but it usually asserts itself as soon as an opening is made. Burns on which the conifers have been completely destroyed often grow up to pure aspen, which in the usual course of succession is later replaced by conifers. Grasses usually are not abundant in the Douglas fir zone, except where the conifers

F-194555

FIGURE 7.—Pure stand of Douglas fir, Mount Graham, Ariz.

have been killed and aspen has not taken possession. The "prairies" of the Apache National Forest furnish another exception, if it may be assumed that this land was ever occupied by trees.

Under cover of the forest, herbaceous vegetation consists mostly of such plants as the sedges (*Carex* spp.), brake (*Peteridium aquilinum pubescens*), vetch (*Vicia americana*), columbine (*Aquilegia* spp.), *Frasera scabra*, and *Helenium hoopesii*. The bunch grasses found in open situations are the same as those in the western yellow pine zone. Either underbrush or aspen is more or less abundant wherever the stand has been thinned by fire or other

agencies. A number of the brush species, including several alders, willows, maples, and locusts, attain tree form under favorable conditions. Of the distinctly shrubby plants, there are a blue and a red elderberry and several species of currant and gooseberry.

The volume, density, and composition of the timber stands vary greatly according to site and locality. In northern New Mexico 8,000 to 10,000 board feet is an average acre yield; in southern New Mexico and southern Arizona, average yields run about 20,000 board feet, and 40,000 feet is not uncommon. Most stands have been thinned by fire. This favors the invasion of western yellow pine in the lower altitudes and limber pine, aspen, and brush higher up. Usually the forest is uneven aged with dense reproduction, often

F-90672

FIGURE 8.—A mixed stand of Douglas fir, western yellow pine, blue spruce, and aspen

made up largely of white fir, under the old stand. Both Douglas fir and white fir attain large size, reaching maximum diameters of 3 to 4 feet, and heights of 140 feet. Mature stands are usually more than 200 years old, and trees 300 to 400 years old are not uncommon.

The average altitudinal limits of the Douglas fir zone range from about 8,000 to 9,500 feet. Since the zone is characterized mainly by steep slopes, aspect is fully as important as altitude and therefore any figures on altitudinal limits over extensive areas can be only rough approximations. Only a small proportion of the land is topographically adapted to agriculture. Rainfall is adequate for most farm crops, but the growing season is too short. Although grazing use is similar to that in the western yellow pine zone, serious damage is less widespread, owing in large measure to the shortness of the grazing season. Extensive lumbering operations are in progress in New Mexico, but very little cutting has been done in this zone in Arizona. Extensive areas in both States were devastated

by fire prior to the establishment of organized protection. The greater portion of these burns has grown up to aspen and will eventually restock to conifers.

ENGELMANN SPRUCE ZONE

Engelmann spruce occupies the highest altitudinal zone of forest growth in the Southwest. (Fig. 9.) Typical Engelmann spruce stands occur almost exclusively on northerly exposures, even at the upper limits of the range. On steep, south-facing slopes and exposed ridges, bristlecone pine or limber pine usually predominates. These sites are so different from those of Engelmann spruce and the firs that where rather close distinctions are desired they are regarded as determining a separate forest type, notwithstanding the fact that a limber pine-bristlecone pine type is not generally recog-

F-41424A

FIGURE 9.—At 11,500 feet, Engelmann spruce still retains tree form but is dwarfed, and the tops above snow level are killed in winter by the terrific blasts of wind, snow, and sleet which cut off the leaves and even the bark on the windward side

nized by the Forest Service. Alpine fir or corkbark fir is a constant companion of the spruce. They are, however, shorter lived and tend to die out in mature stands.

In a dense spruce forest the floor is almost bare of either herbaceous or shrubby vegetation. Since snow is still on the ground well into the month of June, the soil remains moist even on the surface, except for short periods in early summer and in the fall. Mosses and lichens are much in evidence, though they seldom form a mat on the soil. Leaf litter is from 1 to 3 inches deep and usually forms a true leaf mold at the bottom. In the openings a touch of color is added by such plants as columbine, gentian, honeysuckle, and red elderberry. The shrubs and broad-leafed trees are much the same as in the Douglas fir type, but they do not extend to the

upper portion of the Engelmann spruce type. In open situations one finds most of the grasses common to the western yellow pine type, but they are usually dwarfed. In addition, there are several alpine grasses and grasslike species such as *Phleum alpinum*, *Festuca saximontana*, *Trisetum montanum* and *T. spicatum*, *Carex heliophila* and *C. geophila*, and several species of Juncus.

Advance reproduction is present in various stages ranging from seedlings to poles, except under dense, even-aged stands. The well-known ability of spruce and fir to persist when shaded and undernourished enables both of these species to survive for many years under older trees in thickets so dense that growth is almost entirely checked. It is common to find trees of saw-timber size side by side with slender poles, all of nearly the same age. The pines are less able to persist under cover and are therefore absent from the dense stands, particularly on north exposures.

Aspen has much the same status here as in the Douglas fir zone. It takes possession of burns and other openings except toward the upper limits of the type, where it apparently encounters unfavorable conditions. However, spruce and fir, if seed trees survive, reproduce readily under any but an extremely dense aspen cover and eventually regain possession of the soil. Extensive areas in the high mountains of Arizona and New Mexico were swept by fires 40 to 50 years ago. Large portions of these areas have grown up to aspen and as a rule are being restocked by conifers. Most exceptions to this rule may be explained by lack of seed trees, but in a few places other factors appear to dominate. On considerable areas, particularly in the higher altitudes, aspen has not followed the fire. Here grasses and sedges have entered, and conifer reproduction is making slow progress.

Under favorable circumstances the spruce forest is capable of producing heavy stands of timber. The maximum possible yields are rarely realized under natural conditions, however, because of destructive competition in overstocked stands. A 250-year-old stand in the San Francisco Mountains was found to contain a volume of 44,000 board feet to the acre. It was ascertained, however, that originally a considerable proportion of this stand was corkbark fir. This had died out, leaving a pure stand of spruce. (Fig. 10.) Growth during the last half century has been almost at a standstill. The volume, including fir which had died, was probably at least as great at 200 years of age, or even younger, as at 250. A near-by stand of spruce and fir in about equal proportions which proved to be 180 years old, had a volume approximately the same as that on the first area. Although, over large areas the volume in the old forest is much lower, these figures are a good indication of what might be possible in young fully stocked stands under management. In overstocked stands both spruce and fir are small, few trees surpassing 18 inches d. b. h. and 80 feet in height. Free-standing trees reach a diameter of 30 inches and a height of 100 feet.

The Engelmann spruce type has been less exploited than any other type in this region. The stands are mostly inaccessible for logging under present economic conditions. Open situations, such as burns and natural meadows, furnish good summer grazing. There is practically no farming in this type, because of the short growing season and the general unsuitability of living conditions in these high

altitudes. Although the timber resources are important, perhaps the greatest economic value of the Engelmann spruce type is its

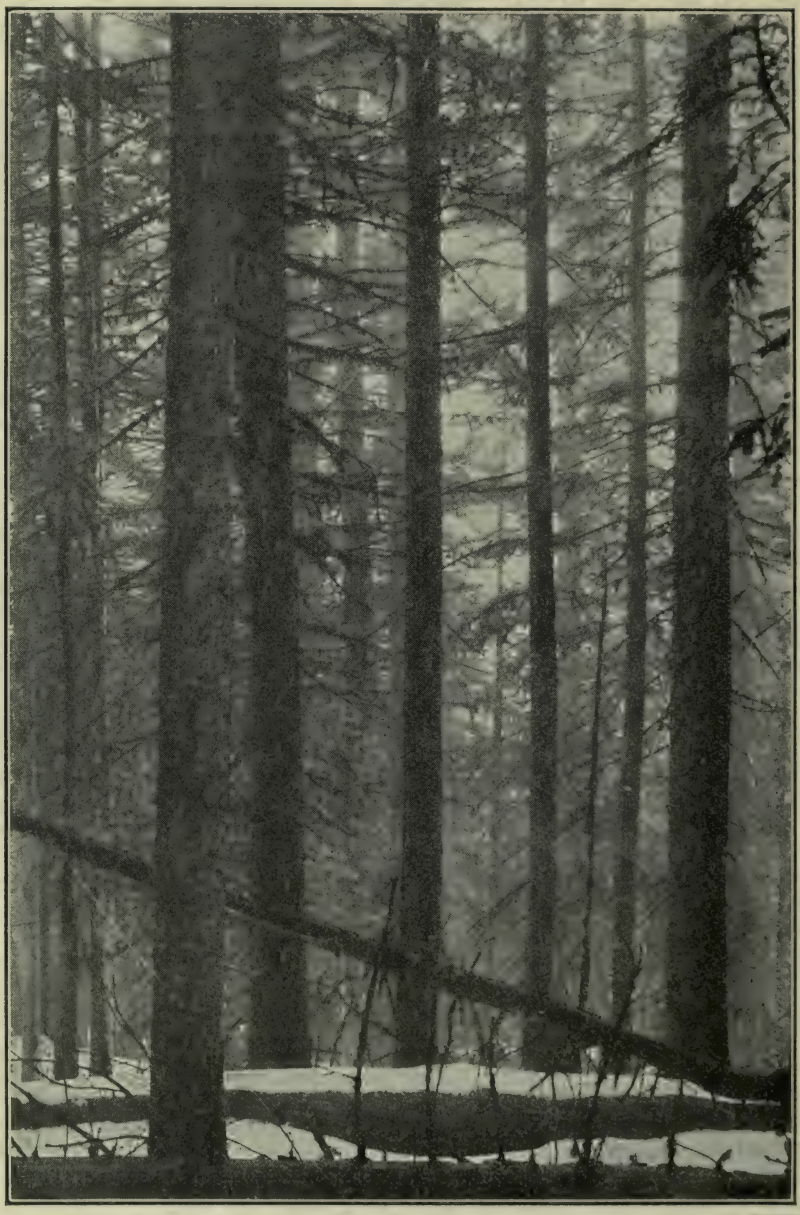

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FIGURE 10.—Pure stand of mature Engelmann spruce 250 years old. Corkbark fir was formerly present, as is indicated by dead and down material

watershed value. Along with the Douglas fir type, it occupies the zone of heavy precipitation from which are fed the streams and underground water sources that mean so much to the Southwest.

CLIMATE

SOURCES OF DATA

The climatological data here presented are mainly from records of the United States Weather Bureau but are supplemented by data obtained from a special investigation carried on by the Southwestern Forest and Range Experiment Station in and near the San Francisco Mountains of northern Arizona. The independent study included measurements of soil temperature and soil moisture. During the summer of 1919, J. O. Veatch of the then Bureau of Soils made a general soil survey in northern Arizona, including detailed examinations of certain areas, in order to establish the relationship between soil and tree growth. Much of the information on soils has been obtained from Veatch's unpublished reports.

WEATHER BUREAU RECORDS

For obvious reasons the sparsely settled high-mountain regions are not so well represented by weather stations as the lower and more densely populated regions. In New Mexico there are, fortunately, several good sets of records for the western yellow pine, Douglas fir, and lower Engelmann spruce types. Arizona, however, has only three stations with continuous records in the western yellow pine zone, two with broken records in the Douglas fir zone, and none in the Engelmann spruce zone. Through the courtesy of Charles E. Linney of the New Mexico section, and Robert Q. Grant of the Arizona section of the Weather Bureau, it was also possible to make use of some records prior to their publication.

Because of the great yearly and periodic variation in precipitation, it was thought necessary to reduce the data from various stations to the same period as far as possible, in order that they might be comparable. This necessitated eliminating some of the oldest records. As a considerable number of the forest weather stations were established about 1909, the precipitation figures here used begin with that year. Regional and type summaries extend only through 1921, although records for individual stations have in many instances been carried through 1926.

Annual means of temperature do not fluctuate widely in successive years, and an average established by 10 years of record will not be departed from more than a degree or two in succeeding periods of similar length. For this reason it is not considered necessary that the periods of temperature observation at different stations be strictly contemporaneous. Most of the temperature summaries given in this bulletin extend to the end of 1921, but they begin at various dates, some more than 40 years ago. Except in the San Francisco Mountain series (which will be discussed later), and in a few other instances, the shortest temperature and precipitation records here used cover a period of six years. Because of the fact that nearly all values given in the tables and graphs represent the average of several stations, abnormalities due to short or noncontinuous records or to unrepresentative locations are in a measure neutralized.

ORIGINAL INVESTIGATIONS

In order to obtain data in the Douglas fir and Engelmann spruce forests in Arizona a series of temporary stations was maintained by the Southwestern Forest Experiment Station from 1917 to 1919, inclusive. This series extended from an elevation of 7,300 feet up the slopes of the San Francisco Mountains to timber line at 11,500 feet, representing the western yellow pine, Douglas fir (fig. 11), limber pine, and Engelmann spruce types and the upper limit of timber growth (fig. 12). A station was also maintained in the piñon-juniper zone, through the cooperation of Forest Ranger W. J. Cox, at Ash Fork, 55 miles west of the San Francisco Mountains. A temporary piñon-juniper station was maintained 15 miles southeast of the San Francisco Mountains during a portion of 1918. In all, there were 12 instrument stations, including 7 designated as substations and maintained during shorter periods in order to compare conditions within forest types. By tying in with Weather Bureau stations in the lower altitudes down to 1,000 feet at Phoenix, it was possible to obtain, within a direct distance of but little more than 100 miles, a series of records representing a vertical range of 10,500 feet and a range of climatic conditions embracing more or less regular gradations from arid-subtropical to humid-alpine.

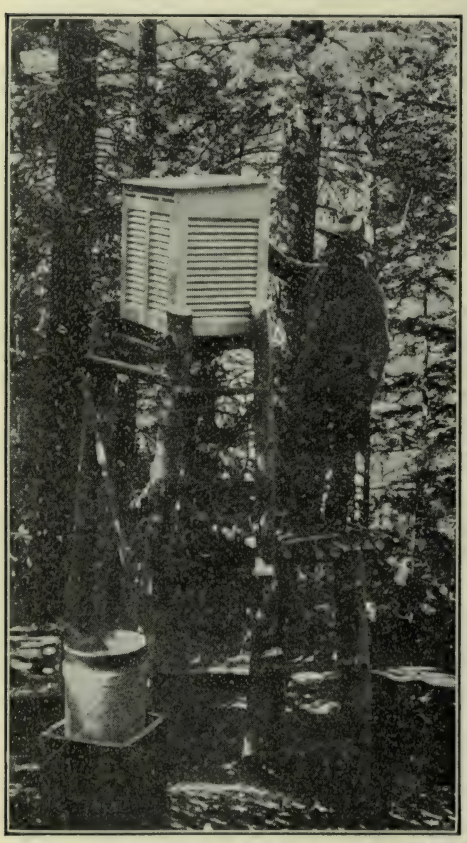

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FIGURE 11.—Douglas fir station 8A

Temperature and precipitation have been correlated with vegetation for this entire chain of stations, and in addition soil temperature and soil moisture were measured in and near the San Francisco Mountains. In presenting this and certain other material, such as temperature summations, the San Francisco Mountains have been treated as a separate unit because comparable data are not available in other sections.

The fact that the San Francisco Mountain records cover only three years may give rise to doubt as to their value, and it should be understood at the outset that no claim is made for these records as a measure of normal climatic conditions. At least 10 years are

required to establish an acceptable norm, according to meteorologists, but they generally accept the principle, which is supported by the results of this investigation, that for the purpose of ascertaining relations between stations in the same locality a much shorter period will suffice. The San Francisco Mountain records are particularly important in this study because they represent true forest conditions. The stations extend nearly 2,000 feet higher than any others in Arizona and New Mexico; since the records were obtained contemporaneously and according to uniform methods,[9] they are directly comparable in the various types concerned; the use of thermographs

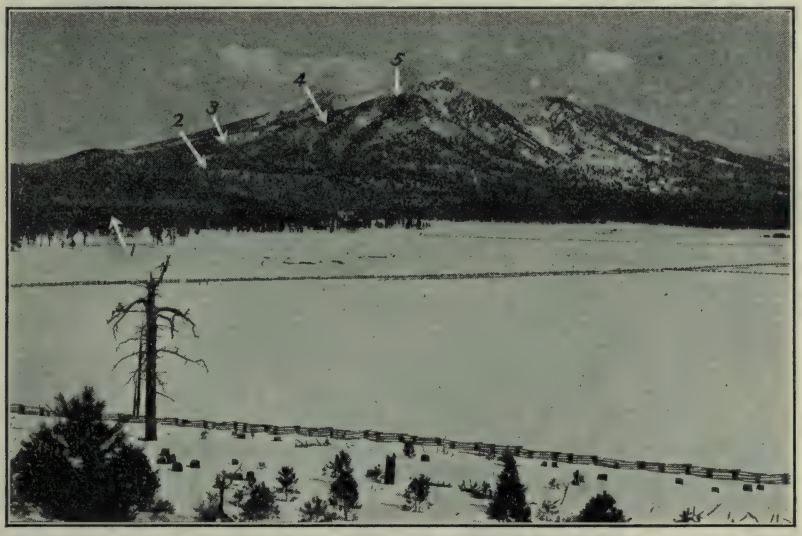

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FIGURE 12.—Fort Valley park and the San Francisco Mountains. The location of the western yellow pine, Douglas fir, limber pine, Engelmann spruce, and timberline meteorological stations is indicated by 1, 2, 3, 4, and 5, repectively

at all stations has made it possible to compile temperature summations which integrate in various ways effective heat values; and the climatic data have been correlated with soil temperature, soil moisture, and vegetation. Their correlation with Weather Bureau

[9] With the exception of those selected to represent open situations, the stations were located in small openings within bodies of virgin forest. It is recognized that from a purely meteorological point of view, it would be preferable to avoid the local influence of forest cover. In this investigation, however, the endeavor is to study conditions as they exist within the forest, particularly with reference to young growth. At all the main stations due consideration was given to air drainage and free exposure to precipitation. The investigations required a weekly visit to each station in order to change thermograph sheets, keep instruments in proper adjustment, and record precipitation, evaporation, soil temperature, and various other data. During the winter months these trips were exceedingly strenuous. Except in 1917–18 the timber-line station could not be reached regularly between October and May. At times, snowstorms delayed the weekly visits to the Douglas fir and Engelmann spruce stations. A number of short breaks in the record are chargeable to this cause and to the occasional failure of instruments to function properly. War conditions brought about frequent changes in the personnel. Obviously the work suffered from these changes, despite close supervision by the writer. The following men served as observers at various times: Emanuel Fritz, Lenthal Wyman, T. S. Hansen, C. E. Behre, S. S. Van Boskirk, L. J. Arnold, J. E. Kintner, and F. W. Haasis. The most exacting and time-consuming part of the work was the compilation of data. This was efficiently handled by Maude E. Wilson during 1918 and 1919, and later by F .W. Hedlund and Eva C. Fleming, who also made extensive compilations of Weather Bureau records.

records covering longer periods will be discussed in the proper connection.

A detailed discussion of the methods of study applied in compiling the records in and near the San Francisco Mountains is given in the Appendix, page 134.

GROUPING OF DATA BY GEOGRAPHICAL DIVISIONS

Because of local differences, mainly in precipitation, the available climatic records were separated into four groups representing the following geographical divisions or regions: (1) Arizona, including all of Arizona except a narrow strip along the eastern border; (2) eastern Arizona and western New Mexico, covering a transition zone extending about 50 miles west and 100 miles east of the Arizona-

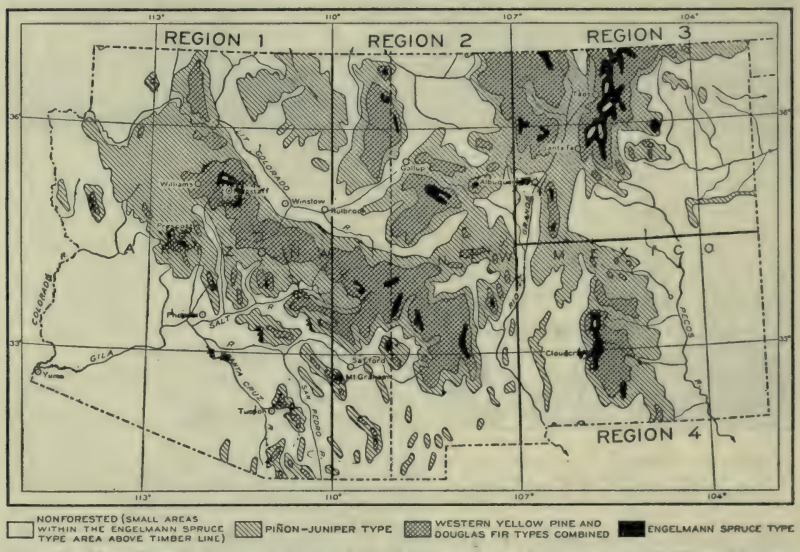

FIGURE 13.—Forest types and precipitation regions of Arizona and New Mexico. (Adapted from Natural Vegetation, a map by H. L. Shantz, Bureau of Plant Industry, and Raphael Zon, Forest Service, U. S. Department of Agriculture)

New Mexico State line; (3) north-central New Mexico; and (4) south-central New Mexico. (Fig. 13.) In addition to the importance of detecting local climatic differences, there is distinct value in the mutual control exercised by several sets of data on the same subject. This is the main reason for dividing New Mexico into a northern and southern region. Arizona might be divided in the same manner but for the fact that there are no adequate records for high altitudes in the southern part of the State. As it is, the data for the southern part are complementary to those of the northern part in that they fill out the lower extreme of the altitudinal series. Northern Arizona, or more specifically the San Francisco Mountain region, is treated as a separate unit with respect to certain data, such as soil temperature, soil moisture, and temperature summations which are not available or have not been compiled for other sections.

THE GROWING SEASON

The beginning and the end of the growing season are generally determined by the presence of sufficient heat for the growth of plants. This season is usually considered to be coincident with the frostless period (Table 1), but it is well known that many plants begin growth before the last frost in spring and are not injured by freezes which are destructive to more tender vegetation.

TABLE 1.—*Duration of frostless period in five forest types in northern Arizona, 1917 to 1919*

Forest type, station, and altitude	1917	Days	1918	Days	1919	Days
Piñon-juniper:						
Cosnino, 6,500 feet			June 1–Sept. 23	115		
Ash Fork, 5,100 feet	June 2–Oct. 18	139	May 31–Oct. 17	140	Apr. 17–Oct. 18	185
Western yellow pine:						
Fort Valley, 7,300 feet	June 13–Sept. 24	104	June 1–Sept. 16	108	June 15–Oct. 2	110
Flagstaff, 6,900 feet	June 7–Sept. 26	112	June 1–Sept. 23	115	June 4–Oct. 3	122
Walnut Canyon, 6,700 feet.	do	112	do	115	do	122
Douglas fir, 8,900 feet	June 3–Oct. 17	137	June 1–Oct. 17	139	June 3–Oct. 2	122
Engelmann spruce, 10,500 feet.	June 6–Sept. 23	110	June 1–Sept. 24	116	June 3–Sept. 28	118
Timber line, 11,500 feet	June 6–Sept. 22	109	June 2–Sept. 22	113	June 14–Sept. 22	101

Several plants in the western yellow pine zone of northern Arizona, among which may be mentioned *Poa fendleriana* and *Thlaspi fendleri*, make their major vegetative growth, blossom, and mature their fruit during the late spring, when frosts occur almost every night. The junipers, the piñon, and western yellow pine make their height growth during May and June, when severe freezes are by no means uncommon. The only native conifer in this region which has been observed to suffer frequently from spring frosts is Douglas fir, and this species is rarely injured in its native habitat. In both the Douglas fir and the Engelmann spruce types, the growing season corresponds closely to the frostless season because here spring growth is retarded by snow. In the western yellow pine and the piñon-juniper types, however, the growing season must be regarded as beginning considerably earlier than the period of no frost.

Cessation of growth in the autumn appears to be as independent of frost as is the inception of growth in the spring. Many plants continue to grow until the leaves are killed by frost; others are not injured by the first frost and continue more or less activity, particularly in the development of fruit, until checked by a severe freeze. But nearly all trees and shrubs in this region cease vegetative activity long before the first autumnal frost. All the conifers complete the development of new shoots and foliage by the middle of August. When diameter growth ceases is not definitely known for all species; in western yellow pine it is practically over by September 1. The high-mountain species mature their cones in September, usually before the first frost; in western yellow pine, however, the cones usually ripen in October after one or more severe freezes have occurred. Broad-leafed trees and shrubs may shed their

leaves without being subjected to freezing temperature, although frost will hasten the process.

In the light of several recent investigations it appears that the growing season may be influenced by a number of factors other than frost. According to the findings of Garner and Allard *(18)*, certain lengths of day favor vegetative growth whereas others favor fruiting. Since these relationships differ for different plants, no generalization can be made; but the possibility that this factor may influence the time when growth ceases is strongly suggested.

It may be assumed that certain temperatures are required for growth, but to determine the minimum growing temperature where many species are involved is no simple matter. Moreover, growing temperatures, even when accompanied by suitable moisture conditions, do not always insure growth. Coville *(15)* has carried on experiments which show that many trees and shrubs indigenous to temperate or cold climates do not continue to grow in the autumn when placed in a greenhouse but shed their leaves and become dormant, as when they are left out of doors. In Arizona, the customary June drought has an important bearing upon seasonal growth. Some plants mature their fruit and become dormant before this drought reaches its height; others show practically no signs of life until the summer rains begin in July. Blue grama belongs to the latter class. It makes only a slight start in May, apparently because of low temperature. In exceptional years when a considerable amount of rain falls in June or the latter part of May, luxuriant growth follows; but under normal conditions dormancy continues through June, the warmest month of the year, and into July, until moisture as well as temperature becomes favorable.

In view of these circumstances it seems futile to attempt to fix the limits of the growing season with any great degree of precision. It is probably 90 days longer in the woodland than in the Engelmann spruce zone, from the standpoint of temperature alone; differences in the intermediate types are gradational. The woodland, however, loses more than 30 days on account of drought, a loss experienced in less degree in the western yellow pine zone and rarely if at all in the Douglas fir and Engelmann spruce zones. In comparing seasonal averages or totals it is convenient to adopt a uniform period for all forest types or vegetational zones, even though this may not always coincide so well as might be desired with the growing season. It is not necessary or even desirable, however, that all factors be summarized for the same months of the growing season. For current air and soil temperature the 4-month period June to September, inclusive, seems better adapted than any other to the main forest types, though it is admittedly inadequate for the woodland and lower zones. In summaries attempting to show the total amount of heat as expressed in temperature summations, however, the difference between types is much more effectively brought out by adding the month of May to the above period, as will be shown in the discussion of this subject. The effect of precipitation, if considerable in quantity, continues several weeks after it falls and therefore growth during June, which is often rainless, may be greatly stimu-

lated by May rains. For this reason, precipitation has been totaled for the period May to September, inclusive.

TEMPERATURES

Through general usage, the term "temperature," when not otherwise qualified, has come to mean temperature of the atmosphere. In such a study as this, however, it is necessary to distinguish between air temperature and soil temperature and also between air temperature and the temperature of the plant. The temperature of the air is measured by placing a thermometer in freely circulating air shielded from the direct rays of the sun. An ordinary thermometer exposed to the sun measures, imperfectly to be sure, the radiant heat energy of the sun rather than the temperature of the air. It is this radiant energy which heats the air, soil, and plants.

AIR TEMPERATURE

Air temperature is the best available index of heat as related to climate. It is also the most readily measured of all climatic factors. Another circumstance which contributes to the value of air temperature as a climatic index is the constancy of averages over long periods of time. Current fluctuations may be great, but when the averages are for periods of a year or longer the variations are seldom more than 10 per cent, whereas precipitation averages, for instance, often fluctuate as much as 100 per cent.

In Tables 2, 3, and 4 the records of several stations in each of the four regions have been combined under the various forest types or vegetational zones. Thus, under each zone the four regions are placed side by side, and the average of the four regions represents the zone over the entire territory covered. The various zones within each region may also be compared in these tables. They are more directly compared in Figures 14, 15, 16, and 17

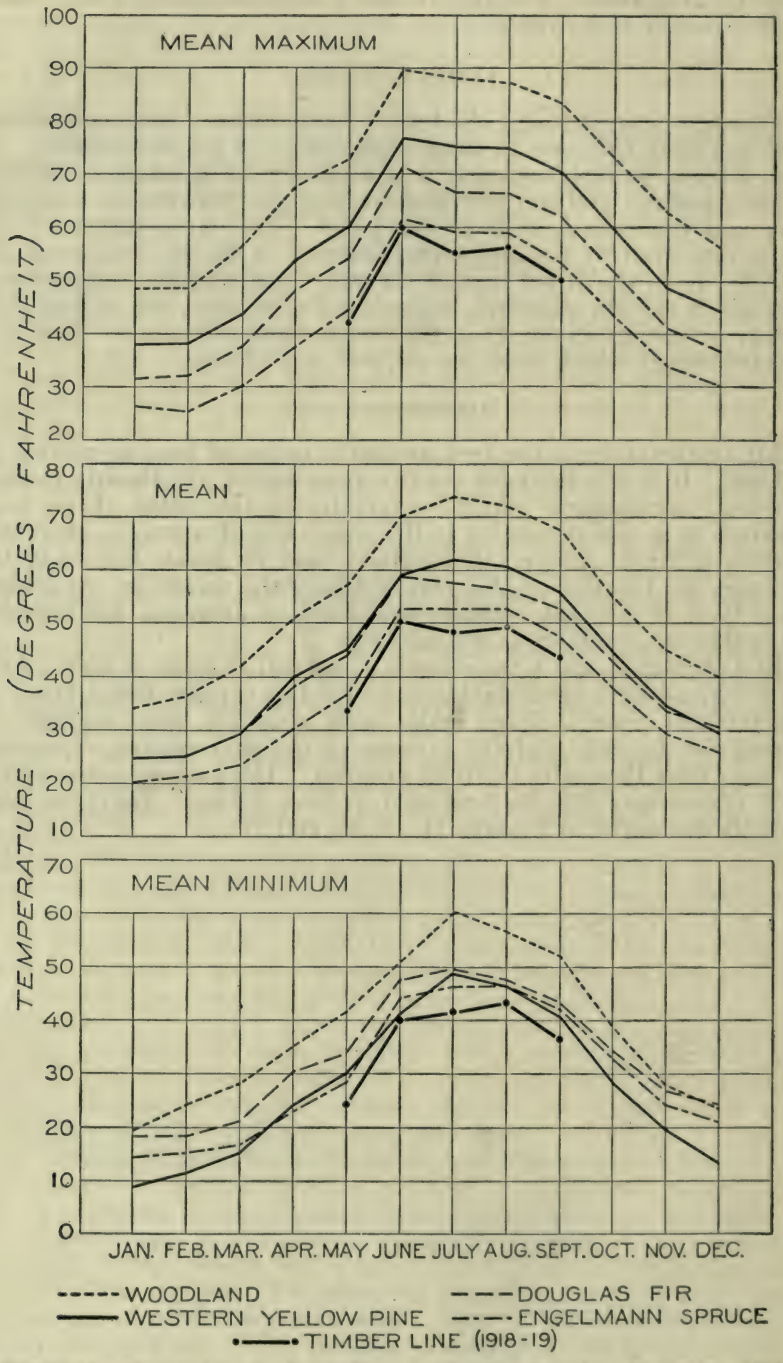

FIGURE 14.—Temperature by forest types in the San Francisco Mountains, 1917 to 1919, inclusive. (Original records)

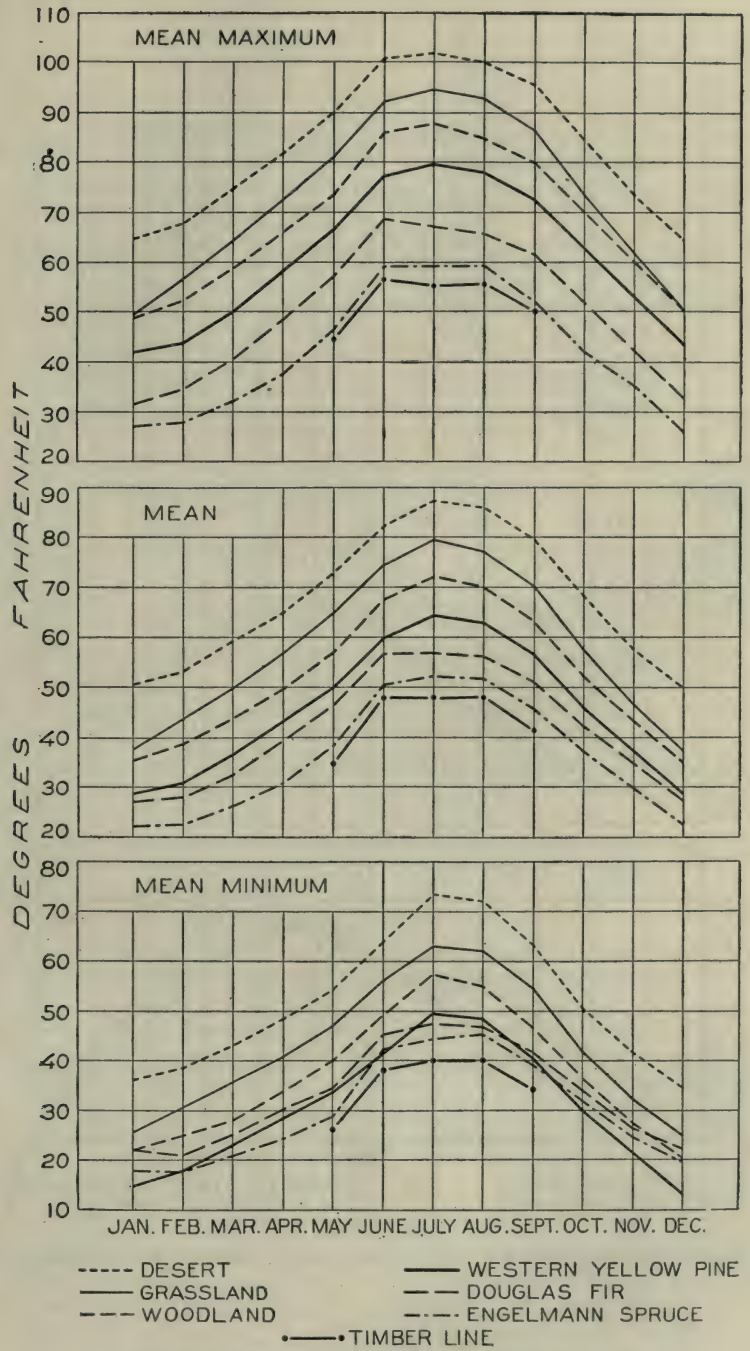

FIGURE 15.—Temperature by forest types, region 1, Arizona

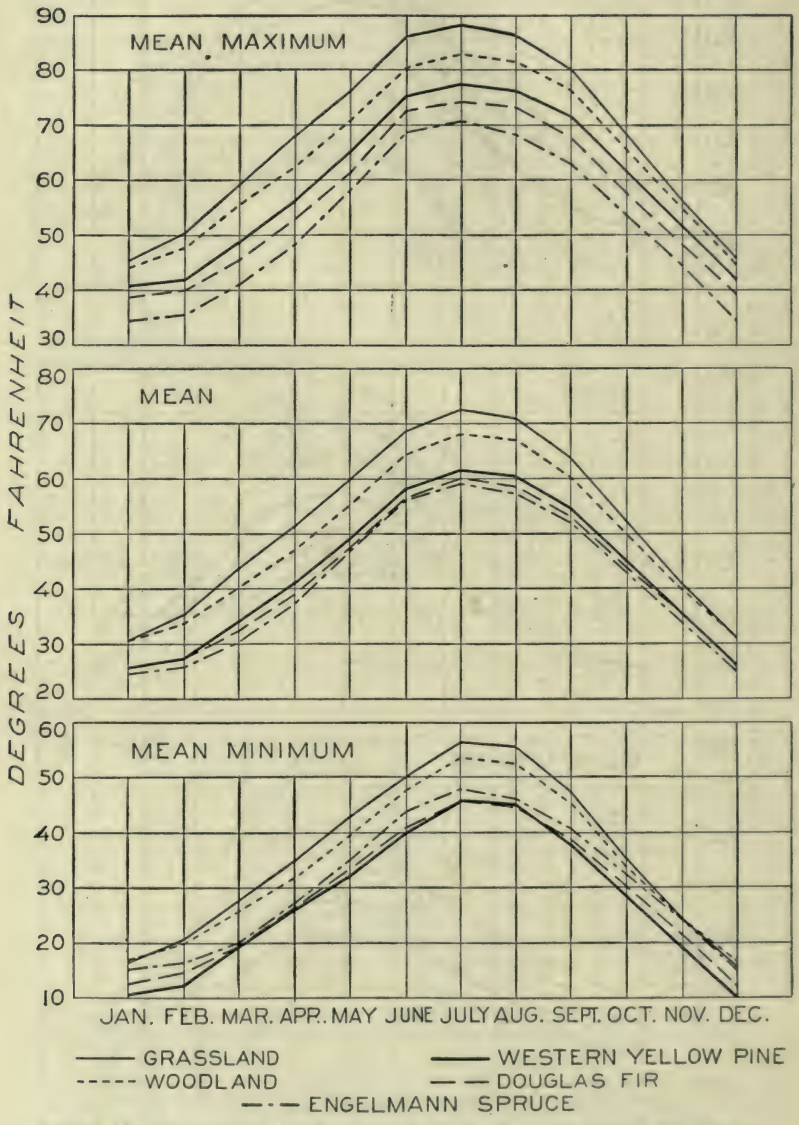

FIGURE 16.—Temperature by forest types, region 3, north-central New Mexico

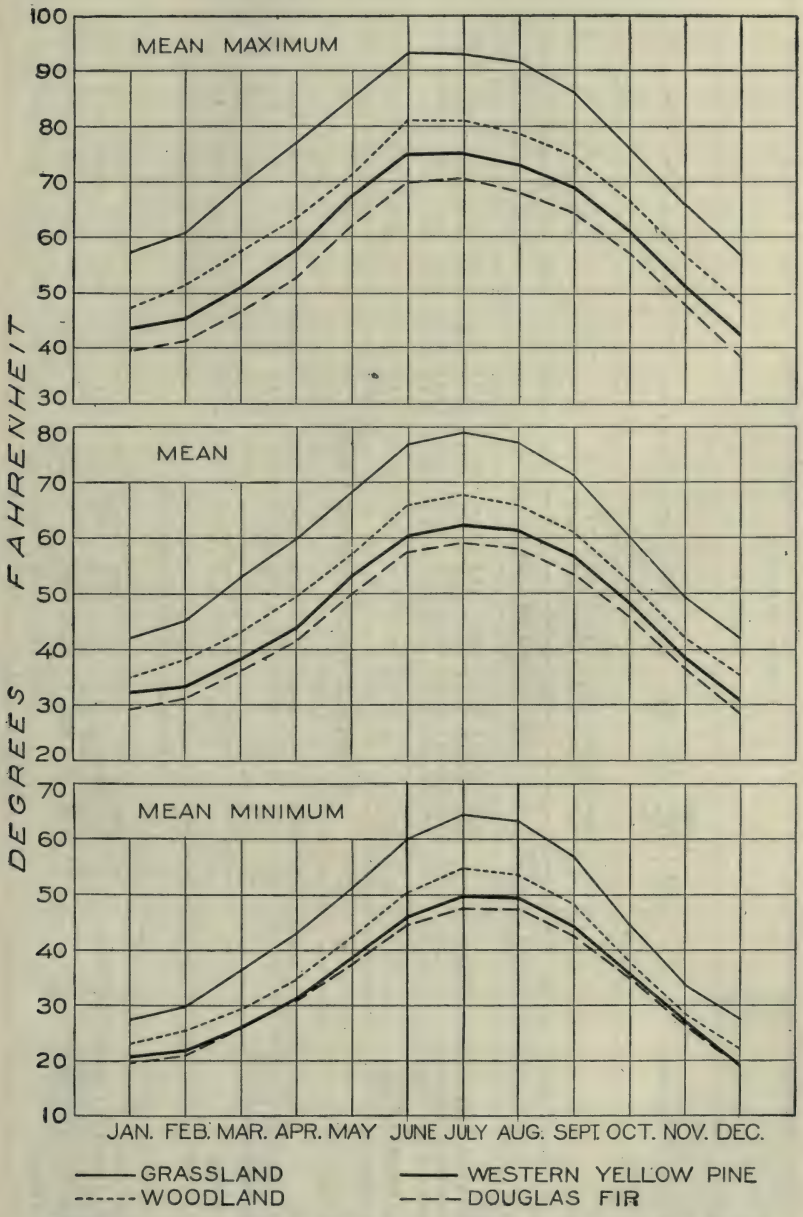

FIGURE 17.—Temperature by forest types, region 4, south-central New Mexico

TABLE 2.—*Mean maximum temperature by months in different vegetational zones and regions in Arizona and New Mexico, average of all years of record*

DESERT

Region No.	Location	Stations [1]	Length range of records	Altitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	June–Sept.
		No.	*Years*	*100 ft.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
1	Arizona	5	8–27	11–24	65.0	67.9	74.4	82.0	90.9	101.1	102.3	100.2	96.1	85.5	74.2	65.0	83.7	99.9

GRASSLAND

1	Arizona	4	12–22	32–48	49.4	56.6	64.6	72.6	81.6	92.5	95.1	93.2	87.2	74.5	62.1	50.5	73.3	92.0
2	Eastern Arizona and western New Mexico	7	6–28	37–56	53.2	58.3	65.8	73.2	82.0	92.3	92.8	90.4	86.1	75.0	63.8	53.0	73.8	90.4
3	North-central New Mexico	5	20–24	49–70	45.4	50.3	59.8	68.2	76.6	86.6	88.5	86.9	80.6	69.1	56.4	45.3	67.8	85.6
4	South-central New Mexico	4	14–32	36–43	57.7	61.0	69.7	77.6	85.6	93.7	93.5	92.0	86.4	76.4	65.9	56.8	76.4	91.4
	Average				51.4	56.6	65.0	72.9	81.4	91.3	92.5	90.6	85.1	73.8	62.0	51.4	72.8	89.8

WOODLAND (PIÑON-JUNIPER TYPE)

1	Arizona	7	6–22	47–69	48.9	52.5	58.8	66.6	73.5	86.2	88.0	85.6	81.1	71.0	60.5	50.4	68.6	85.2
2	Eastern Arizona and western New Mexico	14	3–40	51–70	50.4	53.6	60.1	67.7	76.2	86.2	85.7	83.3	79.2	70.2	60.1	49.7	68.5	83.6
3	North-central New Mexico	8	7–47	61–70	44.6	47.9	55.8	62.8	71.3	80.7	83.0	81.9	76.1	65.6	55.0	44.8	64.1	80.4
4	South-central New Mexico	3	6–22	62–71	47.4	51.2	57.3	63.6	71.5	81.2	81.2	79.0	75.2	66.9	56.9	48.2	65.0	79.2
	Average				47.8	51.3	58.0	65.2	73.1	83.6	84.5	82.4	77.9	68.4	58.1	48.3	66.6	82.1

WESTERN YELLOW PINE ZONE

1	Arizona	3	13–27	67–73	42.1	43.9	49.4	58.0	66.2	77.7	79.8	78.2	73.1	63.4	53.8	43.5	60.8	77.2
2	Eastern Arizona and western New Mexico	5	3–14	65–85	44.4	49.4	54.8	62.0	71.5	82.7	81.7	79.5	75.3	65.4	55.7	45.2	64.0	79.8
3	North-central New Mexico	8	8–18	75–85	40.9	42.0	48.5	56.2	65.2	75.6	77.8	76.3	71.7	61.5	51.8	41.3	59.1	75.4
4	South-central New Mexico	2	11–18	66–86	43.9	45.3	50.8	57.3	67.5	75.2	75.3	73.7	69.7	61.4	50.9	42.3	59.4	73.5
	Average				42.8	45.2	50.9	58.4	67.6	77.8	78.6	76.9	72.4	62.9	53.0	43.1	60.8	76.5

DOUGLAS FIR ZONE

1	Arizona [2]	1	3	89	31.1	32.2	37.6	47.9	54.3	71.6	66.9	66.6	61.9	52.3	40.8	36.7	50.0	66.8
2	Eastern Arizona and western New Mexico	1	5	85	45.9	47.3	52.5	55.6	67.1	76.6	75.5	73.9	71.5	62.1	55.2	43.9	60.6	74.4
3	North-central New Mexico	5	7–18	75–98	38.9	40.2	45.4	52.4	61.5	72.2	74.1	72.8	67.8	58.0	48.9	39.4	56.0	71.7
4	South-central New Mexico	1	18	86	39.8	41.0	46.6	52.7	62.1	70.2	70.9	68.5	64.8	57.0	47.5	38.5	55.0	68.6
	Average				38.9	40.2	45.5	52.2	61.2	72.6	71.8	70.4	66.5	57.4	48.1	39.6	55.4	70.4

LIMBER PINE—BRISTLECONE PINE ZONE

1	Arizona [2]	1	1	100	34.9	28.1	35.7	45.8	53.4	63.4	61.5	63.4	55.7	41.1	37.5	33.7	46.2	61.0

ENGELMANN SPRUCE ZONE

1	Arizona [2]	1	3	105	26.2	25.5	29.8	37.8	44.1	61.4	59.1	59.2	53.2	43.1	34.0	30.2	42.0	58.2
3	North-central New Mexico	2	7–10	94–98	34.5	35.7	40.7	48.3	58.4	68.9	70.4	68.3	63.1	53.8	44.8	34.9	51.8	67.7
	Average				30.4	30.6	35.2	43.0	51.2	65.2	64.8	63.8	58.2	48.4	39.4	32.6	46.9	63.0

TIMBER LINE

1	Arizona [2]	1	2	115					43.5	60.1	55.4	56.4	50.9					55.7

[1] In each zone and region the records obtained from a number of stations at different altitudes and during periods of varying length have been averaged.
[2] Probable departure from 1909–1921 normal of Douglas fir, limber pine-bristlecone pine, Engelmann spruce, and timber-line records is as follows: January, −0.9; February, −2.6; March, −2.6; April, −0.2; May, −2.9; June, +2.2; July, −0.5; August, +0.4; September, +0.3; October, 0.0; November, −2.2; December, +3.8; annual, −0.4; June–September, −0.6.

TABLE 3.—*Mean minimum temperature by months in different vegetational zones and regions in Arizona and New Mexico*

DESERT

Region No.	Location	Stations [1]	Length range of records	Altitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	June–Sept.
		No.	*Years*	*100 ft.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
1	Arizona	5	8–27	11–24	36.5	38.9	43.2	48.1	54.4	63.9	73.2	72.6	65.0	52.6	42.9	35.9	52.3	68.7

GRASSLAND

1	Arizona	4	12–22	32–48	25.3	30.1	35.3	40.6	47.2	56.2	63.7	62.6	55.3	42.6	32.8	25.5	43.1	59.4
2	Eastern Arizona and western New Mexico	7	6–28	37–56	21.7	25.7	30.7	35.5	42.3	51.3	59.6	58.8	51.0	38.3	27.9	21.8	38.7	55.2
3	North-central New Mexico	5	20–24	49–70	16.2	20.5	27.7	35.0	43.2	50.5	56.5	55.1	47.4	35.6	24.4	15.7	35.6	52.4
4	South-central New Mexico	4	14–32	36–43	27.3	30.2	37.0	43.3	51.6	60.6	64.8	63.5	57.0	44.6	33.8	27.4	45.1	61.5
	Average				22.6	26.6	32.7	38.6	46.1	54.6	61.2	60.0	52.7	40.3	29.7	22.6	40.6	57.1

WOODLAND (PIÑON-JUNIPER TYPE)

1	Arizona	7	6–22	47–69	21.4	24.8	28.5	33.6	40.0	49.2	57.0	55.8	48.1	37.2	28.1	21.6	37.1	52.5
2	Eastern Arizona and western New Mexico	14	3–40	51–70	22.1	24.9	29.6	35.0	41.4	50.8	56.1	54.9	48.7	38.2	28.7	21.4	37.6	52.6
3	North-central New Mexico	8	7–47	61–70	17.1	19.9	25.9	31.8	39.4	47.8	53.7	52.3	45.2	34.1	24.3	16.5	34.0	49.8
4	South-central New Mexico	3	6–22	62–71	23.1	25.8	29.5	34.7	42.4	50.7	54.9	53.5	48.1	38.0	28.4	22.7	37.6	51.8
	Average				20.9	23.8	28.4	33.8	40.8	49.6	55.4	54.1	47.5	36.9	27.4	20.6	36.6	51.7

WESTERN YELLOW PINE ZONE

1	Arizona	3	13–27	67–73	14.8	17.3	22.6	28.0	33.3	41.1	49.7	48.9	41.5	30.7	22.4	14.8	30.4	45.3
2	Eastern Arizona and western New Mexico	5	3–14	65–85	14.8	19.4	24.2	29.0	34.5	42.7	50.4	49.2	42.7	31.4	23.1	15.1	31.4	46.2
3	North-central New Mexico	8	8–18	75–85	10.5	12.6	19.6	26.1	32.7	40.0	45.9	45.0	37.8	28.3	19.0	9.9	27.3	42.2
4	South-central New Mexico	2	11–18	66–86	20.7	22.1	26.2	31.2	38.7	46.1	49.9	49.4	44.2	35.8	26.8	19.2	34.2	47.4
	Average				15.2	17.8	23.2	28.6	34.8	42.5	49.0	48.1	41.6	31.6	22.8	14.8	30.8	45.3

DOUGLAS FIR ZONE

1	Arizona [2]	1	3	89	17.8	18.5	21.0	29.5	33.7	47.3	49.1	47.0	43.4	34.6	26.7	23.9	32.7	46.7
2	Eastern Arizona and western New Mexico	1	5	85	12.1	14.1	20.0	23.5	28.9	36.7	44.7	43.6	35.2	26.8	19.3	7.8	26.1	40.0
3	North-central New Mexico	5	7–18	75–98	12.9	14.4	19.7	26.5	33.8	41.2	45.9	44.8	38.6	29.8	21.4	12.1	28.4	42.6
4	South-central New Mexico	1	18	86	19.9	21.2	26.1	30.8	37.4	44.4	47.5	47.5	42.7	34.9	26.3	19.1	33.2	45.5
	Average				15.7	17.0	21.7	27.6	33.4	42.4	46.8	45.7	40.0	31.5	23.4	15.7	30.1	43.7

ENGELMANN SPRUCE ZONE

1	Arizona [2]	1	3	105	13.8	15.3	16.8	23.6	28.3	44.0	46.2	46.5	41.5	32.8	24.0	21.2	29.5	44.6
3	North-central New Mexico	2	7–10	94–98	15.2	16.5	20.0	27.2	35.5	43.8	47.7	46.0	41.0	32.5	24.3	15.3	30.4	44.6
	Average				14.5	15.9	18.4	25.4	31.9	43.9	47.0	46.2	41.2	32.6	24.2	18.2	30.0	44.6

TIMBER LINE

1	Arizona [2]	1	2	115					25.8	40.6	41.6	41.5	36.7				40.1

[1] In each zone and region the records obtained from a number of stations at different altitudes and during periods of varying length have been averaged.

[2] Probable departure from 1909–1921 normal of Douglas fir, Engelmann spruce, and timber-line records is as follows: January, −4.4; February, −2.3; March, −4.0 April, −0.4; May, −0.4; June, +1.9; July, +1.3; August, −0.3; September, +1.1; October, +0.1; November, −1.4; December, +0.8; annual, −0.7; June–September, +1.0.

TABLE 4.—*Mean temperature by months in different vegetational zones and regions in Arizona and New Mexico*

DESERT

Region No.	Location	Stations [1]	Length range of records	Altitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	June–Sept.
		No.	*Years*	*100 ft.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
1	Arizona	5	8–27	11–24	50.8	53.4	58.8	65.0	72.6	82.5	87.8	86.4	80.6	69.0	58.6	50.4	68.0	84.3

GRASSLAND

1	Arizona	4	12–22	32–48	37.4	43.4	50.0	56.6	64.4	74.4	79.4	77.9	71.2	58.6	47.4	38.0	58.2	75.7
2	Eastern Arizona and western New Mexico	7	6–28	37–56	37.4	42.0	48.2	54.4	62.2	71.8	76.2	74.6	68.6	56.6	45.8	37.4	56.3	72.8
3	North-central New Mexico	5	20–24	49–70	30.8	35.4	43.8	51.6	59.9	68.6	72.5	71.0	64.0	52.4	40.4	30.5	51.7	69.0
4	South-central New Mexico	4	14–32	36–43	42.5	45.6	53.4	60.4	68.6	77.2	79.2	77.8	71.7	60.5	49.8	42.1	60.7	76.5
	Average				37.0	41.6	48.8	55.8	63.8	73.0	76.8	75.3	68.9	57.0	45.8	37.0	56.7	73.5

WOODLAND (PIÑON-JUNIPER TYPE)

1	Arizona	7	6–22	47–69	35.2	38.6	43.6	50.1	56.8	67.7	72.5	70.7	64.6	54.1	44.3	36.0	52.8	68.9
2	Eastern Arizona and western New Mexico	14	3–40	51–70	36.2	39.2	44.8	51.4	58.8	68.5	70.9	69.1	64.0	54.2	44.4	35.6	53.1	68.1
3	North-central New Mexico	8	7–47	61–70	30.8	33.9	40.8	47.3	55.4	64.2	68.4	67.1	60.6	49.8	39.6	30.6	49.0	65.1
4	South-central New Mexico	3	6–22	62–71	35.2	38.5	43.4	49.2	57.0	66.0	68.0	66.2	61.6	52.4	42.6	35.4	51.3	65.4
	Average				34.4	37.6	43.2	49.5	57.0	66.6	70.0	68.3	62.7	52.6	42.7	34.4	51.6	66.9

WESTERN YELLOW PINE ZONE

1	Arizona	3	13–27	67–73	28.4	30.6	36.0	43.0	49.8	59.4	64.8	63.6	57.3	47.0	38.1	29.2	45.6	61.3
2	Eastern Arizona and western New Mexico	5	3–14	65–85	29.6	34.4	39.5	45.5	53.0	62.7	66.0	64.4	59.0	48.4	39.4	30.2	47.7	63.0
3	North-central New Mexico	8	8–18	75–85	25.7	27.3	31.0	41.2	49.0	57.8	61.8	60.6	54.8	44.9	35.4	25.6	43.2	58.8
4	South-central New Mexico	2	11–18	66–86	32.3	33.7	38.5	44.2	53.1	60.6	62.6	61.6	57.0	48.6	38.8	30.8	46.8	60.4
	Average				29.0	31.5	37.0	43.5	51.2	60.1	63.8	62.6	57.0	47.2	37.9	29.0	45.8	60.9

DOUGLAS FIR ZONE

1	Arizona [2]	1	3	89	24.4	25.4	29.3	38.7	44.0	59.4	58.0	56.8	52.6	43.4	33.8	30.3	41.3	56.7
2	Eastern Arizona and western New Mexico	1	5	85	29.0	30.7	36.2	39.6	48.0	56.6	60.1	58.8	53.4	44.4	37.2	25.8	43.3	57.2
3	North-central New Mexico	5	7–18	75–98	25.9	27.3	32.6	39.4	47.6	56.7	60.0	58.8	53.2	43.9	35.2	25.8	42.2	57.2
4	South-central New Mexico	1	18	86	29.8	31.1	36.4	41.8	49.8	57.3	59.2	58.0	53.8	46.0	36.9	28.8	44.1	57.1
	Average				27.3	28.6	33.6	39.9	47.4	57.5	59.3	58.1	53.2	44.4	35.8	27.7	42.7	57.0

ENGELMANN SPRUCE ZONE

1	Arizona [2]	1	3	105	20.0	20.4	23.3	30.7	36.2	52.7	52.6	52.8	47.4	38.0	29.0	25.7	35.7	51.4
3	North-central New Mexico	2	7–10	94–98	24.8	26.1	30.4	37.8	47.0	56.4	59.0	57.2	52.0	43.2	34.6	25.1	41.1	56.2
	Average				22.4	23.2	26.8	34.2	41.6	54.6	55.8	55.0	49.7	40.6	31.8	25.4	38.4	53.8

TIMBER LINE

1	Arizona [2]	1	2	115					34.6	50.4	48.5	49.0	43.8					47.9

[1] In each zone and region the records obtained from a number of stations at different altitudes and during periods of varying length have been averaged.

[2] Probable departure from 1909–1921 normal of Douglas fir, Engelmann spruce, and timber-line records is as follows: January, −2.6; February, −2.4; March, −3.3; April, −0.3; May, −1.6; June, +2.0; July, +0.4; August, 0.0; September, +0.7; October, 0.0; November, −1.8; December, +2.3; annual, −0.6; June–September, +0.8.

Temperature in Different Forest Types of the Same Region

In the comparison of temperatures in the several forest types of region 1 given in Tables 2, 3, and 4 and Figures 14 and 15 (to which records for the desert, grassland, and alpine-sedge land (timber line) have been added to show the extreme range), the outstanding feature is the irregular decrease in the mean minimum [10] temperature from the lowest to the highest altitudes in contrast with the regular decrease in the mean maximum. This irregularity in the mean minimum is most conspicuous in the relation between the western yellow pine, Douglas fir, and Engelmann spruce types. In the western yellow pine forests at Fort Valley and Flagstaff nights are often colder by several degrees in the winter and autumn months than in the Douglas fir and Engelmann spruce forests. (Table 5.) This phenomenon, known in meteorology as temperature "inversion," is not uncommon in mountain regions. It is merely a manifestation of the well-known fact that cold air tends to drain off the high places and settle in the low places. In this case all the stations are situated so as to avoid stagnation of the air as far as possible, but the mountain stations are on much steeper slopes than the western yellow pine and lower stations and therefore have better air drainage.

Table 5.—*Lowest temperatures, by months, at various stations in northern Arizona, 1918*

Forest type, station, and altitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Grassland:	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Kingman, 3,300 feet	21	21	28	27	35	49	53	50	51	38	24	11
Winslow, 4,800 feet	−9	12	18	17	30	40	52	44	38	23	14	−1
Piñon-juniper, Ash Fork, 5,100 feet	0	14	23	24	31	41	50	46	37	27	11	9
Western yellow pine:												
Williams, 6,700 feet	−3	2	12	18	21	28	39	35	26	18	0	−7
Flagstaff, 6,900 feet	−13	3	11	16	18	32	42	36	25	16	−4	−10
Fort Valley, 7,300 feet	−13	4	6	15	12	33	40	34	25	15	−4	−10
Douglas fir, 8,900 feet	−2	4	14	18	23	39	43	41	33	20	8	−2
Engelmann spruce, 10,500 feet	−6	2	9	13	19	35	39	38	32	17	2	−6
Timber line, 11,500 feet	−3	−2	9	5	13	30	34	33	29	10	2	------

Although the lowest night temperatures frequently occur at relatively low altitudes, the lowest day temperatures are found at the highest altitudes, as may be readily sensed by the mountain climber without the aid of instruments. As one ascends the slopes of a high mountain, the nights become little if any colder, but the days are decidedly colder. In the spruce forest the temperature in winter sometimes remains below freezing continuously for a week at a time, and in summer it rarely reaches 70° F. It is the low day tempera-

[10] The terms "mean maximum," "mean minimum," and "mean" temperature are used in conformity with Weather Bureau usage. The mean maximum temperature is the arithmetical average of the daily maxima. Usually the mean maximum is computed for each month, and the average of all the monthly mean maxima gives the mean maximum for the year. The mean minimum temperature is computed in the same way as the mean maximum. Mean temperature is designed to express the average temperature for the day, month, or year. The daily mean is usually calculated by taking the mean of the highest and lowest readings for the day. The monthly or annual mean is the arithmetical average of the daily means for the period involved, and also of the mean maximum and the mean minimum for the month or year.

tures, as reflected largely in the maxima, that constitute the vital heat deficit in the high altitudes.

The question has been raised whether the Douglas fir, Engelmann spruce, and timber-line records in the San Francisco Mountains, covering only three years, are comparable with the longer records in the western yellow pine and lower zones. Reference has already been made to the irregularities in the mean minimum. This condition, however, also appears in the New Mexico series (figs. 16 and 17) in which the Douglas fir and Engelmann spruce records cover 10 years or more and, in the case of figure 16, are the average of several stations. The point at issue is, to what extent do the 1917–1919 records in the Douglas fir and Engelmann spruce types and at timber line represent normal temperature conditions for this locality? An attempt has been made to answer the question by ascertaining how closely the 1917–1919 records in the western yellow pine type correspond to the records for a longer period.

Footnote 2 in Tables 2, 3, and 4 gives the monthly departures of the 1917–1919 means from the 1909–1921 norm at the control station in the western yellow pine type of the San Francisco Mountains. According to the annual means, the 1917–1919 period averaged 0.6° F. colder than normal. The greatest monthly departure from the norm was −4.4° in the minimum temperature for January. Further inspection shows that generally the departures are greatest in the minimum temperature and during the winter months. These figures are thought to be fairly accurate indices of seasonal and annual normality, but they are probably less reliable when applied to a single month. For this reason, the writer has hesitated to correct the monthly means in Tables 2, 3, and 4. In Figure 15, however, the monthly departures have been applied to the Douglas fir, Engelmann spruce, and timber-line records. The effect in general has been to harmonize the graphs. A notable exception is the minimum temperature for January. Figure 14 is plotted from the original data, the period of 1917–1919 being used in all types. It should be noted that these graphs are almost as regular as those based on longer periods in Figure 15.

From the foregoing analysis it is concluded that the Douglas fir, Engelmann spruce, and timber-line records obtained in the San Francisco Mountains in 1917–1919 and presented in Tables 2, 3, and 4 are directly comparable to records for the same period from other stations in the same region; but that if it is desired to compare these records with those for longer periods in the same or different regions, the departures indicated in the footnotes to Tables 2, 3, and 4 should be applied. As has previously been stated, however, too much reliance should not be placed on these departures as corrections for single months. This precaution is especially necessary with regard to minimum temperatures, for which there appears to be no such thing as a norm in mountain regions. This erratic behavior of the minimum presents a problem which apparently can not be wholly solved by long-time records. Inversions which cause the minimum-temperature graphs of the Douglas fir and Engelmann spruce types to cross

and recross that of the western yellow pine type should be regarded as representing actual conditions rather than as being faulty records.

VARIATIONS IN THE WESTERN YELLOW PINE ZONE

During a period of five years (from 1909 to 1913, inclusive), air temperature, precipitation, wind, humidity, and evaporation were measured by the writer (*31*) in the Fort Valley park, a flat, treeless valley more than a mile in diameter, bordering the forest in which a permanent meteorological station is maintained. The records show daily maximum temperatures averaging 0.9° F. higher in the valley than in the forest. Daily minima averaged 6.4° lower and were often as much as 10° or 15° lower in the park than in the forest. The slightly higher day temperatures in the treeless area are attributed to better insolation, and the extremely low night temperatures in the park are due in part to absence of tree crowns to reduce radiation but mainly to drainage of cold air into the valley, which is from 25 to 50 feet lower than the surrounding forest.

In another locality, about 12 miles farther south, away from the immediate influence of the mountains, temperature was measured in 1910 at two stations about a quarter of a mile apart, similarly situated as to topography, but one in a virgin stand of western yellow pine and the other on an adjoining area where practically all the trees had been removed by logging. Here, as at Fort Valley, mean maximum temperature averaged about 1° F. higher in the open situation; but the minimum temperatures, instead of being many degrees lower in the open, were only from 2° to 3° lower. Evidently the reduction of radiation by the tree canopy was primarily responsible for the higher minimum temperatures in the forest.

The data available indicate that low temperatures become more moderate as the distance from high mountains increases. Thus Flagstaff, situated 8 miles farther from the San Francisco Mountains and only 400 feet lower than Fort Valley, has mean minimum temperatures averaging 2.7° F. higher than the latter station. At Williams, 30 miles farther from the San Francisco Mountains and only 150 feet below Flagstaff altitudinally, minimum temperatures average 1.9° higher than in Flagstaff. Both Flagstaff and Williams are so situated that they receive cold-air drainage from the surrounding country. But the nearest mountain to Williams, although not more than 5 or 6 miles distant, reaches an altitude of only 9,250 feet above sea level, or 3,500 feet less than that of the San Francisco Mountains.

VARIATIONS IN THE DOUGLAS FIR ZONE

In the Douglas fir zone of the San Francisco Mountains, contemporaneous records for different situations in the same locality are not available. In 1911 and 1912, however, records were kept during the summer months at a station about 2 miles distant from the one employed in the 1917–1919 series. As compared with the Fort Valley records, both stations show about the same general relation, namely, lower maxima but higher minima. The Douglas fir type through Arizona and New Mexico occurs almost invariably in rugged country, usually on slopes or benches and rarely, if ever,

on broad, flat mesas characteristic of the western yellow pine type of the Colorado Plateau. The only situations in the Douglas fir zone which might be subject to abnormally low temperatures are the bottoms of canyons and a few basins.

VARIATIONS IN THE ENGLEMANN SPRUCE ZONE

The main Engelmann spruce station was on a steep northwest slope of the San Francisco Mountains in one of the heaviest pure stands of mature spruce in the Southwest. During 1919 and 1920, supplementary records were kept in an opening 150 feet in diameter on a ridge about 100 yards directly above the main spruce station. The ridge at this point is about 200 feet wide and breaks off to the south into steep, grassy slopes where spruce, corkbark, fir, and bristlecone pine grow in clumps. Table 6 gives the mean maximum and mean minimum temperatures by months at the northwest slope and the ridge stations. The outstanding differences between the two stations is the much higher day temperature and lower night temperature on the ridge. These differences are caused in part by absence of tree cover at the ridge station.

TABLE 6.—*Comparison of temperatures on a ridge and a steep northwest slope, by months, 1919*

MEAN MAXIMUM TEMPERATURE

Station No.	Forest type and exposure	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	June to Sept.
	Engelmann spruce:	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
10B	Ridge	43.2	51.6	65.9	60.2	62.8	55.3	39.4	33.9	29.2	61.0
10A	Northwest slope	40.0	48.5	62.1	58.5	60.3	52.2	36.2	32.8	29.9	58.3
	Timber line:										
11A	Ridge	------	48.1	60.7	55.9	59.0	49.6	------	------	------	56.3
11B	Northwest slope	------	------	62.0	55.5	58.5	50.4	------	------	------	56.6

MEAN MINIMUM TEMPERATURE

	Engelmann spruce:										
10B	Ridge	24.3	32.3	41.7	45.6	45.2	39.7	25.7	22.2	17.2	43.0
10A	Northwest slope	25.2	33.1	43.1	47.1	47.4	41.2	26.1	23.6	20.1	44.7
	Timber line:										
11A	Ridge	------	29.0	37.7	41.9	43.3	36.3	------	------	------	39.8
11B	Northwest slope	------	------	36.1	43.6	43.0	36.1	------	------	------	39.7

VARIATIONS AT TIMBER LINE

The main timber-line station was on a ridge about 100 yards wide, facing the southwest. In the preliminary report on this investigation (*32*), the subnormal development of the trees at this station is attributed to wind rather than to low temperature. On the northwest slope, just over the ridge about 100 yards from the ridge station, the spruce timber stops abruptly, there being practically no transition zone of bushy or trailing spruce beyond the line of erect trees, as is the case on the ridge. A thermograph was operated just outside the timber line during the months of June, July, August, and September, 1919. The difference in both mean maximum and mean minimum at the two stations (Table 6) is very slight and fluctuates

from month to month. Wind movement during October, 1918, was more than twice as great on the ridge as on the slope. (Table 17).

Although regions 2, 3, and 4 have not been studied in the same detail as region 1, available information indicates a similar relation between forest types. Region 3, which has satisfactory records up to the lower portion of the Engelmann spruce type, shows the same uniform decline in maximum temperature and the same irregular decline in the minima from the lower to the higher zones, with frequent inversions between the western yellow pine and the Engelmann spruce types. The minima in region 4 lack much of the irregularity found in regions 1 and 3, but the records extend only to the lower portion of the Douglas fir type.

Temperature of the Same Forest Type in Different Regions

In comparing physical conditions of a given forest type in different regions allowance must be made for a number of circumstances which operate against absolute harmony. In the first place, more or less variation is known to exist within a given type even in the same locality; therefore, a station near the upper limit of a type in Arizona would be expected to show conditions somewhat different from those at a station near the lower limits of the same type in New Mexico. The main discrepancy, however, arises from the fact that some of the records which it has been necessary to use are not truly representative. Even when a type in a given locality is represented by several stations the compensating influence of averages may not always overcome the difficulty. In north-central New Mexico, for instance, all three stations listed under Engelmann spruce are too near the lower edge of this type to give a true expression of conditions prevailing generally in the Engelmann spruce forest.

Tables 2, 3, and 4 show a reasonably close agreement between the four regions, considering the deficiency of data in some instances. In the grassland, woodland, and western yellow pine zones the stations are most numerous, and here the agreement is closest. The wide discrepancies in the records for Douglas fir and Engelmann spruce are attributable partly to incomplete or unrepresentative data. The Douglas fir type is well represented in northern New Mexico; in each of the other three localities it has but one station. In contrast to the Engelmann spruce stations in northern New Mexico, all of which are too near the lower border of the type, the one station in Arizona is well located, and its records, although they cover only three years, are probably more representative of temperature conditions in the Engelmann spruce type.

The general course of the graphs in Figures 14, 15, 16, and 17, for the several regions is very similar except for the month of June, when those for Arizona shoot upward in a manner which suggests abnormality. Doubtless the sharp rise in the Douglas fir and Engelmann spruce graphs for Arizona is exaggerated in degree, but that it represents a real condition is indicated by the fact that it is also present in the western yellow pine and piñon-juniper graphs, both based on a period of 13 years. This rapid rise in temperature during the month of June is apparently directly associated with the

dry, clear weather which usually prevails in Arizona during this month, but which is less pronounced in New Mexico. The disappearance of snow on the mountains may also be a factor, especially in minimum temperatures.

Excepting the grassland, which covers a very wide range of conditions, and the Engelmann spruce type, in which data are very limited, the extreme differences within a type are rarely more than 6° F. As a rule there is closer agreement during the growing season than in winter.

Temperature Summations

As a measure of heat in relation to plant growth, the mean temperature, whether it be the daily, monthly, or annual mean, is unsatisfactory because night temperatures, which may be neutral as far as growth is concerned, are weighed against effective day temperatures.[11] In the San Francisco Mountains of northern Arizona, the mean annual temperature from 1917 to 1919, inclusive, was 41.5° F. in the Douglas fir type and 42.2° in the western yellow pine type. This variation of 0.7° would indicate differences too small to be of any consequence; yet any one familiar with conditions surrounding the two stations from which these records were obtained can not fail to note a most profound difference in both temperature and vegetation. Further inquiry into the records shows strikingly lower day temperatures and higher night temperatures in the Douglas fir zone than in the western yellow pine zone. Thus it comes about that when the daily maxima and minima are averaged, nearly the same mean daily temperature is obtained in both types. This close relation exists only during the winter, spring, and fall months. In winter, the Douglas fir station sometimes shows a mean monthly temperature actually higher than that of the yellow pine station, but during July, August, and September there is a wide margin in favor of the western yellow pine zone.

Further inspection of the graphs in Figures 14, 15, 16, and 17 brings out very clearly the disturbing effect of inversions in minimum temperature upon the daily mean. The graphs for mean maximum temperature, however, are remarkably free from irregularities. The uniform relation between mean maximum temperatures of various stations observed in all records in the Southwest has led the writer to regard this factor as far more reliable than mean temperature as an index of temperature relations. This view is strengthened by the indications, which will be discussed later, that in this particular study maximum values are of far more importance than minimum values. The mean maximum provides a good measure of the highest intensities attained, but it does not take into account the duration of these intensities.

Several schemes designed to integrate intensity and duration of temperature have been devised. As usually employed, however, these methods do not give adequate expression to intensity, because they are based on the mean daily temperature.

[11] Clements and Weaver (*14*) have improved on the conventional method of computing mean temperature by separating day means from night means.

Merriam (*29, p 54, f. n. 2*) used a method which he described as follows:

> In computing the sum of the positive or effective temperatures a minimum temperature of 6° C. (43° F.) has been assumed as marking the inception of the period of physiological activity in plants and of reproductive activity in animals. The effective temperatures or degrees of normal mean daily heat in excess of this minimum have been added together for each station, beginning when the normal mean daily temperature rises higher than the 6° C. in spring and continuing until it falls to the same point at the end of the season. The sums thus obtained were platted on a large scale map of the United States and connected by isotherms, which were found to conform in the most gratifying manner with the northern boundaries of the several life zones.

The minimum temperature referred to in the above description as marking the lower limit of physiological activity is in reality the lowest daily mean. In other words, when the computed daily mean falls below 43° F. the temperature for that day is regarded as ineffective, notwithstanding that there may have been several hours when the current temperature was above 43°. Evidently it is not assumed that 43° marks the lower limit of growth, but rather that when the daily mean is below this point effective temperatures are not likely to occur. In some investigations 42° and in others 32° have been used instead of 43°. When one considers the variation in heat requirements in different plants, any minimum limit must be regarded as more or less arbitrary. In spite of its shortcomings, the most obvious of which are the uncertain significance of mean temperature and the variability in minimum heat limits, this method was used effectively by Merriam 30 years ago in what is still regarded as an authoritative work on temperature integration in its relation to the distribution of plants and animals.

Another method, known as the exponential indices,[12] is based upon the principle of Van't Hoff and Arrhenius that the velocity of chemical reaction approximately doubles with a rise in temperature of 18° F. The indices of temperature efficiency are calculated on the assumption that general plant activity occurs at unity rate when the daily mean temperature is 40° and that this rate is doubled with each rise of 18° in the daily mean. This principle seems to apply only within certain limits of temperature, even in purely chemical problems; the limitation is probably still greater when applied to plant growth. In addition, the method is open to criticism because it employs the mean daily temperature instead of the actual temperature during the hours of major physiological activity.

Probably the most effective method of integrating temperature is what is known as the physiological indices of temperature efficiency, based upon experiments by Lehenbauer (*24*). In these experiments, maize seedlings were grown at different temperatures, and the rate of growth during a period of 12 hours was carefully measured for all. The temperatures were in regular gradations of 1°, ranging from 12° to 43° C. Thus, one lot of plants was grown at 12°, another at 13°, another at 14°, and so on through the scale. Lehenbauer found that 32° was the optimum temperature for growth under the conditions surrounding his plants, but he also stated that the optimum is without meaning unless duration as well as intensity

[12] The review of this method and of the physiological indices method is taken largely from Livingston and Shreve (*26*).

is considered. Livingston, using Lehenbauer's data as a basis, has prepared a table, reproduced here as Table 7, giving growth values corresponding to each single degree of temperature from 36° to 118° F., considering the growth at 40° as unity. According to this table, the rate of growth increases with rise in temperature up to 89° and then falls off gradually, reaching the zero point at 118.4°. A logical development of this method for studies in forestry would be to determine the physiological indices of growth for forest trees instead of maize seedlings. Until this is done there can be no assurance that it provides a better expression of temperature with reference to tree growth than is afforded by some of the simpler methods.

TABLE 7.—*Physiological indices of temperature efficiency for growth, based on Lehenbauer's 12-hour exposures with maize seedlings*[1]

Temperature	Index	Temperature	Index	Temperature	Index	Temperature	Index	Temperature	Index	Temperature	Index
°F.		°F.		°F.		°F.		°F.		°F.	
36	0.111	50	6.333	64	30.000	78	90.667	92	113.444	106	21.889
37	.222	51	7.111	65	33.333	79	95.000	93	108.333	107	16.778
38	.342	52	8.167	66	37.222	80	98.667	94	103.333	108	12.556
39	.667	53	9.222	67	41.333	81	103.000	95	96.000	109	9.444
40	1.000	54	10.333	68	46.000	82	106.889	96	91.444	110	7.000
41	1.333	55	11.667	69	50.833	83	110.778	97	85.000	111	5.222
42	1.667	56	12.778	70	56.000	84	115.000	98	79.444	112	3.778
43	2.000	57	14.444	71	60.333	85	118.111	99	73.111	113	2.778
44	2.344	58	16.111	72	65.333	86	120.000	100	66.667	114	2.000
45	3.000	59	17.778	73	69.000	87	121.222	101	60.000	115	1.444
46	3.500	60	19.883	74	73.667	88	122.000	102	52.667	116	1.000
47	4.000	61	22.000	75	78.111	89	122.333	103	44.444	117	.500
48	4.778	62	24.333	76	82.333	90	121.667	104	36.000	118	.111
49	5.500	63	27.111	77	86.556	91	117.667	105	28.667		

[1] From (*26*).

Proper application of the table of physiological indices calls for a true measure of air temperatures, which is not afforded by the daily mean. It should be borne in mind that Lehenbauer's experiments were conducted with plants exposed to constant temperatures. The growth rate given for a temperature of 60° F. means a constant temperature of this intensity, not an average of readings ranging from 40° to 80°. The efficiency corresponding to a daily mean temperature of given magnitude may be far different from that obtained by summing the indices for the various components of this daily mean. Where thermograph records are available, errors from this source may be greatly reduced by dividing the day into short periods of uniform length, determining the efficiency of each separately, and taking the average of these values as the efficiency for the entire day. The 2-hour intervals marked on standard thermograph sheets are convenient and are probably sufficiently short for most purposes, although a change of as much as 30° is sometimes recorded in two hours. The values obtained in this way are entered in column 5 of Table 8, and those derived from the daily mean temperature are entered in column 4. It is evident that the two sets of values bear no constant relation to each other. The writer has no hestitation in saying that the values computed from 2-hour temperature means are the more reliable. In the western yellow pine type, the differences are much greater than in the Engelmann spruce type, owing probably to a greater daily range in the pine type. In fact, the differences

in the spruce forest are rather small, and this suggests that in climates of even temperature the daily mean might give fairly good results.

TABLE 8.—*Comparison of physiological temperature efficiency computed from daily means and means for 2-hour periods, 1918*

WESTERN YELLOW PINE ZONE

Date	Daily temperature		Physiological efficiency		Date	Daily temperature		Physiological efficiency	
	Maximum	Mean	Based on mean daily temperature	Based on temperature by 2-hour periods		Maximum	Mean	Based on mean daily temperature	Based on temperature by 2-hour periods
	°F.	°F.				°F.	°F.		
June 1	68.8	52.8	9.22	17.22	June 19	78.0	63.4	27.11	31.71
2	75.5	54.2	10.33	28.01	20	79.0	63.4	27.11	43.10
3	75.7	56.5	12.78	31.23					
4	77.0	56.3	12.78	37.97	Total or mean	81.1	64.95	384.59	407.17
5	76.2	57.0	14.44	38.73					
6	79.0	58.4	16.11	39.04	June 21	77.8	66.2	37.22	28.80
7	77.7	60.2	19.88	41.22	22	70.0	61.2	22.00	21.00
8	77.5	59.6	19.88	37.47	23	73.5	62.8	27.11	28.65
9	83.0	63.2	27.11	51.50	24	77.6	61.4	22.00	33.47
10	86.3	67.2	41.33	56.97	25	81.0	64.8	33.33	42.46
					26	83.3	67.4	41.33	61.48
Total or mean	77.7	58.5	183.86	379.36	27	83.5	70.5	56.00	68.45
					28	86.8	65.7	37.22	55.90
June 11	88.9	68.8	50.83	66.12	29	83.5	66.2	37.22	42.95
12	88.2	68.0	46.00	45.87	30	82.1	64.0	30.00	36.46
13	81.9	66.4	37.22	44.29					
14	81.2	65.4	33.33	40.56	Total or mean	80.5	65.0	343.43	421.62
15	76.6	62.0	24.33	31.22					
16	76.9	62.5	24.33	31.99	Monthly total or mean	79.75	62.8	861.88	1,208.15
17	81.0	66.2	37.22	37.77					
18	79.0	63.4	27.11	34.54					

ENGELMANN SPRUCE ZONE

June 1	50.0	42.4	1.67	1.74	June 19	59.0	53.5	10.33	8.62
2	58.0	49.5	6.33	5.29	20	62.0	54.5	10.33	13.13
3	58.5	50.2	6.33	5.75					
4	61.1	50.5	6.33	6.74	Total or mean	64.8	56.1	139.20	124.28
5	60.0	52.6	9.22	7.62					
6	59.5	51.8	8.17	6.94	June 21	57.0	51.5	8.17	7.10
7	59.9	53.0	9.22	7.39	22	53.8	48.4	4.78	4.88
8	57.0	50.1	6.33	5.73	23	55.0	49.5	6.33	4.42
9	62.0	55.4	11.67	11.55	24	59.2	51.8	8.17	8.31
10	68.0	59.6	19.88	16.94	25	61.0	55.0	11.67	10.49
					26	70.8	61.6	24.33	25.95
Total or mean	59.4	51.5	85.15	75.69	27	70.8	63.9	30.00	28.23
					28	71.1	62.4	24.33	22.26
June 11	71.1	62.7	27.11	24.94	29	66.0	58.0	16.11	13.42
12	72.4	60.2	19.88	15.91	30	61.3	55.6	12.78	10.66
13	65.8	57.9	16.11	13.44					
14	63.0	53.5	10.33	11.02	Total or mean	62.6	55.8	146.67	135.72
15	63.0	52.7	9.22	7.87					
16	63.0	54.0	10.33	8.43	Monthly total or mean	62.3	54.45	371.02	335.69
17	63.8	55.9	12.78	10.44					
18	65.0	56.0	12.78	10.48					

Tables 9, 10, and 11 give temperature summations by different methods and for different periods in the five forest types, as does also Figure 18. The records necessary for these summations are available for the highest forest types only in the series of stations in the San Francisco Mountains. Physiological temperature efficiencies were computed by 2-hour periods. The duration of various temperatures was taken directly from the thermograph sheets, by simply determining the number of hours the graph was above or below any designated temperature line. A refinement of this scheme, which

may be called the area method, measures by means of a planimeter the actual area lying between the temperature graph and any designated line on the thermograph sheet. In the last column of Table 11 is given the area or product of intensity by duration above the 42° F. line. Summations have also been made for longer intervals than June to September because they furnish a more complete expression of effective temperature conditions during a possible growing season.

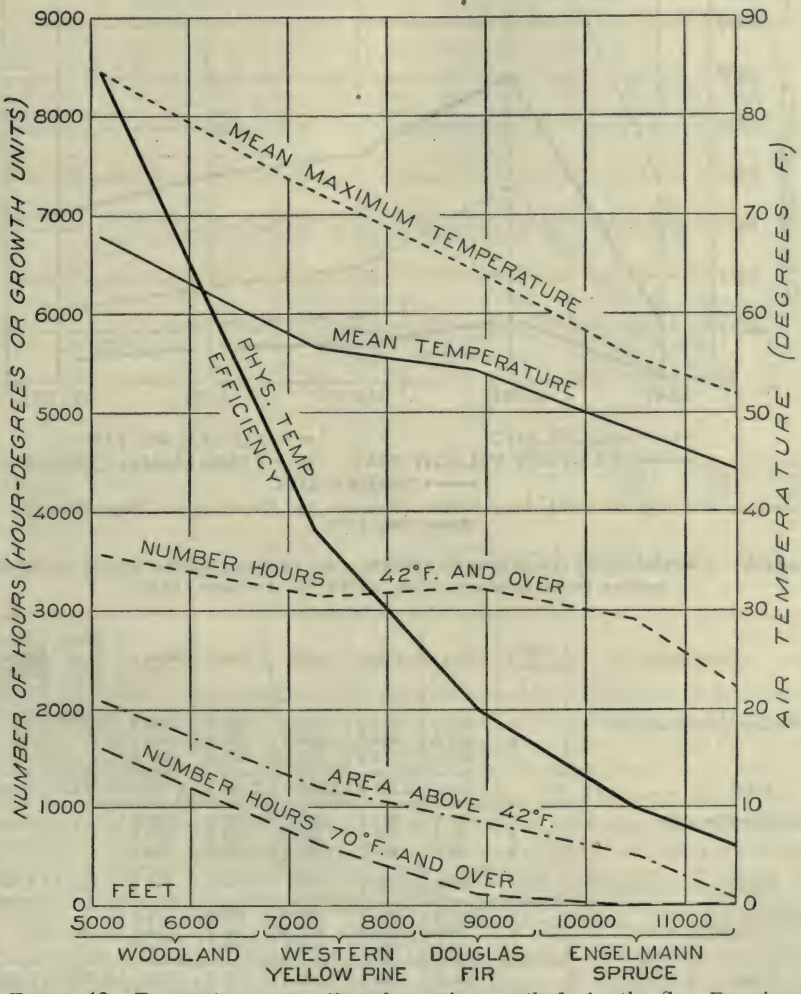

FIGURE 18.—Temperature summations by various methods in the San Francisco Mountains, May–September, 1918

When May is included, as in Table 9 (column 8) and in Figure 19, the seasonal physiological efficiency is increased substantially in the piñon-juniper type and considerably in the western yellow pine type, but increasingly less as altitude increases, until it becomes negligible when the Engelmann spruce type is reached. Table 10, which includes both May and October, shows the same relation with respect to the duration of temperatures above 42° but in less degree with respect to temperatures above 70°.

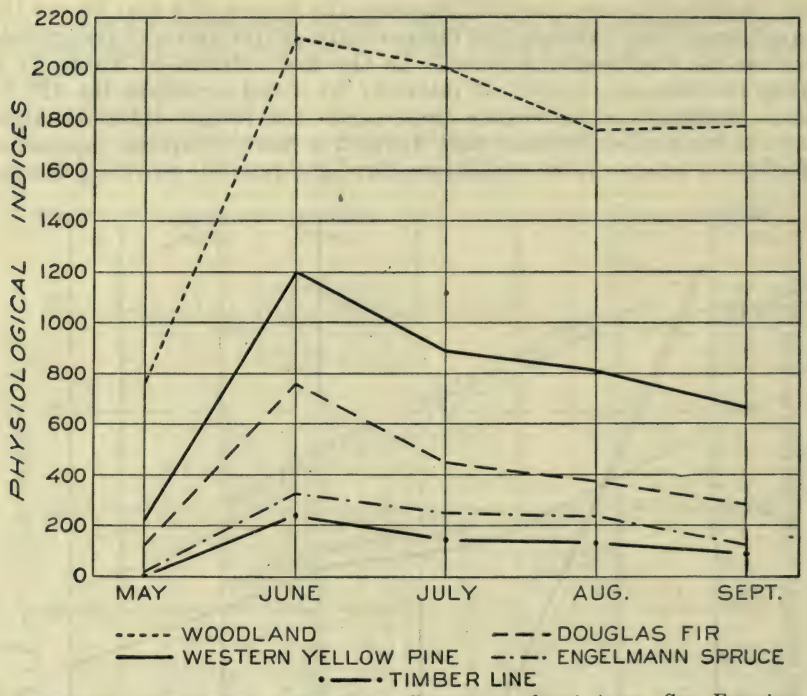

FIGURE 19.—Physiological temperature efficiency by forest types, San Francisco Mountains, 1918

TABLE 9.—*Physiological temperature efficiency by 10-day periods, based on 2-hour means from thermograph, northern Arizona, 1918*

Forest type	10-day period	May	June	July	Aug.	Sept.	Total May–Sept.	Total June–Sept.
Woodland (piñon-juniper)	1	269.0	655.5	598.2	578.6	602.0		
	2	248.0	698.3	597.6	422.4	644.4		
	3	247.5	759.2	808.4	761.2	522.1		
Total		764.5	2,113.0	2,004.2	1,762.2	1,768.5	8,412.4	7,647.9
Western yellow pine	1	74.9	379.4	273.2	254.9	171.3		
	2	76.5	407.2	239.6	183.0	308.8		
	3	83.6	421.6	380.9	378.5	188.1		
Total		235.0	1,208.2	893.7	816.4	668.2	3,821.5	3,586.5
Douglas fir	1	37.6	254.9	122.9	135.0	74.8		
	2	46.0	262.8	117.8	83.2	132.8		
	3	50.5	245.9	206.9	160.7	76.0		
Total		134.1	763.6	447.6	378.9	283.6	2,007.8	1,873.7
Engelmann spruce (northwest slope)	1	6.1	75.7	66.1	90.4	36.9		
	2	6.9	124.3	64.4	43.2	54.7		
	3	8.6	135.7	129.1	[1] 116.0	[1] 36.0		
Total		21.6	335.7	259.6	249.6	127.6	994.1	972.5
Timber line (ridge)	1	5.4	59.8	34.1	42.4	17.0		
	2	2.4	[1] 86.0	37.9	13.9	49.6		
	3	3.7	[1] 104.0	73.8	81.5	18.9		
Total		11.5	249.8	145.9	137.8	85.5	630.5	619.0

[1] Interpolated.

TABLE 10.—*Duration of various temperatures in northern Arizona, 1918*

Forest type	Hours during June to September at—				Hours during May to October at—				Hours during November to April at—			
	32° F. or less	Less than 42° F.	42° F. or more	70° F. or more	32° F. or less	Less than 42° F.	42° F. or more	70° F. or more	32° F. or less	Less than 42° F.	42° F. or more	70° F. or more
Woodland	0	5	2,923	1,489	16	240	4,176	1,829	(1)	(1)	(1)	(1)
Western yellow pine	21	203	2,725	633	287	860	3,566	657	2,191	3,152	1,192	0
Douglas fir	0	62	2,866	134	158	766	3,650	134	2,111	3,726	618	0
Engelmann spruce	0	150	2,778	4	462	1,205	3,211	4	3,172	4,168	176	0
Timber line	24	753	2,175	1	779	2,092	2,324	1	(1)	(1)	(1)	(1)

[1] No record.

TABLE 11.—*Temperature summations by different methods for five forest types in northern Arizona, May to September, inclusive, 1918*

Forest type	Mean temperature	Mean maximum temperature	Duration, 42° F. and above	Duration, 70° F. and above	Physiological temperature efficiency	Product of intensity by duration [1] above 42° F.
	°F.	°F.	*Hours*	*Hours*		
Woodland	68.1	84.4	3,577	1,629	8,412	2,089.2
Western yellow pine	56.5	72.2	3,155	633	3,822	1,206.6
Douglas fir	54.3	64.7	3,231	134	2,008	863.4
Engelmann spruce	48.3	55.9	2,922	4	994	511.8
Timber line	44.4	51.9	2,212	1	630	321.9

[1] Area described by the thermograph above the 42° line obtained by planimeter.

SOIL TEMPERATURE

Soil temperature has received relatively little attention as compared with air temperature and moisture. Records are not available over extensive regions, as they are for air temperature and precipitation. Though little is known regarding the effects of soil temperature upon plant life, that it must exert a considerable influence, within certain limits at least, is obvious. Plants can not absorb moisture from a soil that is frozen. Frozen soil associated with a dry atmosphere is thought to be a common cause of winterkilling. Observations of western yellow pine seedlings have shown that root growth does not begin until the temperature of the soil in the afternoons reaches a point well above 40° F. It is known that root growth in this and other species begins earlier in the spring than does the growth of aerial portions of the tree. It is also known that the temperature of the soil has a considerable influence upon chemical action and the activity of soil organisms.

In this study measurements of soil temperature were confined to the San Francisco Mountains and vicinity. Records in the piñon-juniper type cover only a single growing season, but those in the western yellow pine, Douglas fir, and Engelmann spruce types extend over three or more years. These records are presented in Table 12.

TABLE 12.—*Mean soil temperature by months at different depths by forest types, San Francisco Mountains*

1918 RECORDS

Depth and forest type	Station No.	Altitude	Shade	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	June–Sept.
6 inches:		*Feet*	*Per cent*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
Western yellow pine	1A	7,300	25	28.5	28.4	35.8	42.8	50.5	63.4	62.4	62.6	60.3	51.8	37.5	30.7	46.2	62.2
Douglas fir	8A	8,900	60	31.7	29.7	32.1	34.1	43.4	55.2	53.8	52.7	48.7	42.4	33.4	31.0	40.7	52.6
Engelmann spruce	10A	10,500	90	------	------	------	------	------	41.2	45.6	45.0	42.7	37.5	------	------	------	43.6
12 inches:																	
Piñon-juniper	3	5,100	0	[1]40.0	[1]38.0	46.8	56.0	63.7	[1]73.0	[1]75.0	75.4	75.3	64.8	------	------	------	------
Western yellow pine	1C	7,300	0	33.5	31.1	35.6	46.7	56.6	65.4	65.3	65.9	63.6	[1]58.0	41.1	32.7	49.6	65.0
Do	1A	7,300	25	32.1	30.4	35.2	41.6	47.9	58.6	60.2	60.3	58.0	51.9	39.2	32.7	45.7	59.3
Do	1B	7,300	60	31.4	29.9	34.3	39.6	44.4	56.1	58.4	57.4	54.4	[1]48.0	37.3	33.1	43.7	56.6
Douglas fir	8A	8,900	60	32.4	30.9	32.4	33.7	41.3	53.0	53.5	52.2	48.7	44.0	35.3	32.7	40.8	51.8
Engelmann spruce	10A	10,500	90	28.3	28.0	29.7	30.6	31.6	39.4	45.5	45.3	43.4	39.3	31.8	30.0	35.2	43.4
Timber line	11A	11,500	0	------	------	------	------	------	39.3	47.1	47.5	46.4	41.1	31.5	------	------	45.1
24 inches:																	
Western yellow pine	1C	7,300	0	[1]35.5	[1]33.0	36.6	45.2	54.1	62.5	63.6	64.6	63.2	[1]59.5	43.7	36.8	49.9	63.5
Do	1A	7,300	25	34.8	32.2	35.3	40.0	46.3	53.8	58.2	58.3	57.4	53.9	41.6	36.5	45.7	56.9
Do	1B	7,300	60	33.6	32.5	35.2	39.6	49.1	52.7	56.7	57.2	55.7	50.0	40.3	35.6	44.8	55.6
Douglas fir	8A	8,900	60	33.8	31.9	32.8	33.6	40.1	49.7	52.0	51.6	48.8	44.5	37.1	34.4	40.9	50.5
Engelmann spruce	10A	10,500	90	30.1	29.3	30.2	30.8	31.6	35.7	43.3	44.4	43.3	40.3	33.8	31.1	35.3	41.7

1919 RECORDS

12 inches:																	
Western yellow pine	1C	7,300	0	30.2	29.9	33.0	44.0	56.6	64.4	65.3	65.8	63.1	48.4	38.5	35.0	47.8	64.6
Do	1A	7,300	25	27.5	28.7	31.0	38.9	47.7	56.1	60.3	60.1	58.0	46.2	37.0	34.1	43.8	58.6
Do	1B	7,300	60	29.7	30.5	31.2	37.9	46.2	53.6	59.2	58.7	55.6	44.2	37.3	34.8	43.2	56.8
Western yellow pine (upper limit)	8C	8,800	0	32.8	32.3	33.0	36.6	42.9	54.7	57.6	57.5	55.9	42.5	36.4	35.2	43.1	56.4
Douglas fir (aspen)	8B	8,900	40	32.3	32.1	32.2	34.1	45.4	51.1	54.6	55.4	53.2	42.1	35.7	34.3	41.9	53.6
Douglas fir	8A	8,900	60	30.5	30.5	30.9	32.6	42.7	52.1	53.4	53.6	49.6	39.1	34.3	34.0	40.3	52.2
Limber pine-bristlecone pine	9	10,000	0	28.9	33.2	29.3	35.0	45.7	55.1	55.8	54.6	53.7	41.6	36.4	34.3	42.0	54.8
Engelmann spruce (northwest slope)	10A	10,500	90	26.9	27.9	28.3	30.7	32.6	40.8	46.9	46.9	44.8	34.9	32.5	32.3	35.5	44.8
Engelmann spruce (ridge)	10B	10,500	25	32.4	30.9	31.7	32.1	38.1	52.1	52.8	56.4	50.9	38.2	33.8	32.9	40.2	53.0
Timber line (ridge)	11A	11,500	0	------	------	------	------	33.0	39.8	46.6	49.1	46.4	35.5	------	------	------	45.5
Timber line (northwest slope)	11B	11,500	0	------	------	------	------	32.1	41.2	45.9	46.4	43.0	33.1	------	------	------	44.1

AVERAGE FOR 1917 TO 1919, INCLUSIVE

12 inches:																	
Western yellow pine	1A	7,300	25	30.4	30.0	32.7	38.8	47.8	57.4	60.2	60.2	58.0	49.9	39.2	34.0	44.9	59.0
Do	1B	7,300	60	30.7	30.3	32.3	37.3	43.8	54.1	58.7	58.1	55.3	47.1	38.2	34.1	43.3	56.6
Douglas fir	8A	8,900	60	31.0	30.5	31.2	32.8	39.9	51.1	53.4	52.8	48.9	42.1	35.9	33.6	40.3	51.6
Engelmann spruce	10A	10,500	90	28.2	28.4	29.0	30.7	32.1	38.1	44.8	45.9	43.7	37.5	32.6	31.2	35.2	43.1
24 inches:																	
Western yellow pine [2]	1A	7,300	25	33.2	31.6	33.6	38.6	45.5	52.8	58.2	58.4	57.5	51.5	40.7	36.4	44.8	56.7
Do [3]	1B	7,300	60	33.1	32.4	33.2	37.0	44.7	50.9	56.3	57.1	55.6	49.7	40.6	36.1	43.9	55.0
Douglas fir	8A	8,900	60	32.8	32.0	31.9	32.9	38.2	47.4	51.9	51.9	48.9	43.1	37.6	35.0	40.3	50.0
Engelmann spruce	10A	10,500	90	29.8	29.3	29.7	31.0	31.8	35.1	42.1	44.5	43.6	38.9	34.4	32.3	35.2	41.3

1913 RECORDS

24 inches:																	
Western yellow pine (forest)	1B	7,300	60					41.7	49.2	54.8							
Western yellow pine (park)		7,250	0					52.1	61.1	65.9							

[1] Interpolated.
[2] 1918 and 1919 only.
[3] Incomplete 1919.

Relation Between Air and Soil Temperature

Soil temperature bears a fairly consistent relation to air temperature when the two are compared over rather long periods, but current variations often do not agree. For depths below about 6 inches, diurnal fluctuations in the soil are often directly contrary to those of the air because several hours are required to transmit surface change to the lower soil strata. Except in a thin surface layer, the temperature of the soil is much more constant than that of the air. Diurnal variations in soil and air temperature, according to thermograph records, are shown in Figure 20.

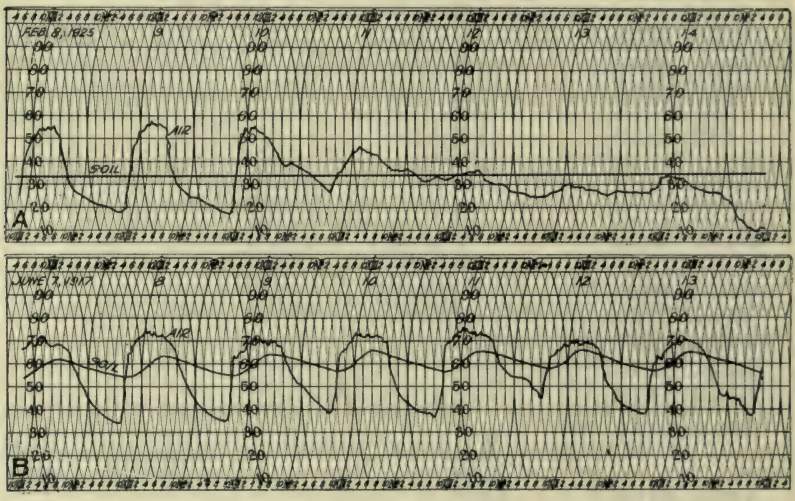

Figure 20.—Thermograph records of air temperature 8 feet above and soil temperature 6 inches below ground surface, western yellow pine type, Fort Valley, Ariz.: A, In winter, snow 6 inches deep, February 8–10 clear, February 11–15 cloudy; B, in summer

Effect of Cover, Slope, and Aspect

Soil temperature is influenced by both air temperature and the intensity and duration of direct solar radiation. As a medium for absorbing and retaining heat, the soil surpasses the air. Where exposed to the sun it is usually warmer than the air at the surface and not infrequently considerably below the surface. This is also usually the case in the fall when a deep blanket of snow covers the ground before it becomes deeply frozen. In the western yellow pine type, however, the mean temperature curve for the air falls below the soil curve long before the arrival of snow. (Fig. 21.)

Whenever cloudy skies or mechanical obstructions cut off a considerable proportion of the solar radiation the effect is reflected in the lowering of soil temperature. The effect of shade cast by tree crowns in lowering soil temperature is strikingly illustrated in Table 12 and Figure 22. Direction and steepness of slope are other important modifying factors. Southerly aspects are always warmer than northerly ones of the same gradient, and a steep slope of southerly exposure is warmer than a gentle or moderate one.

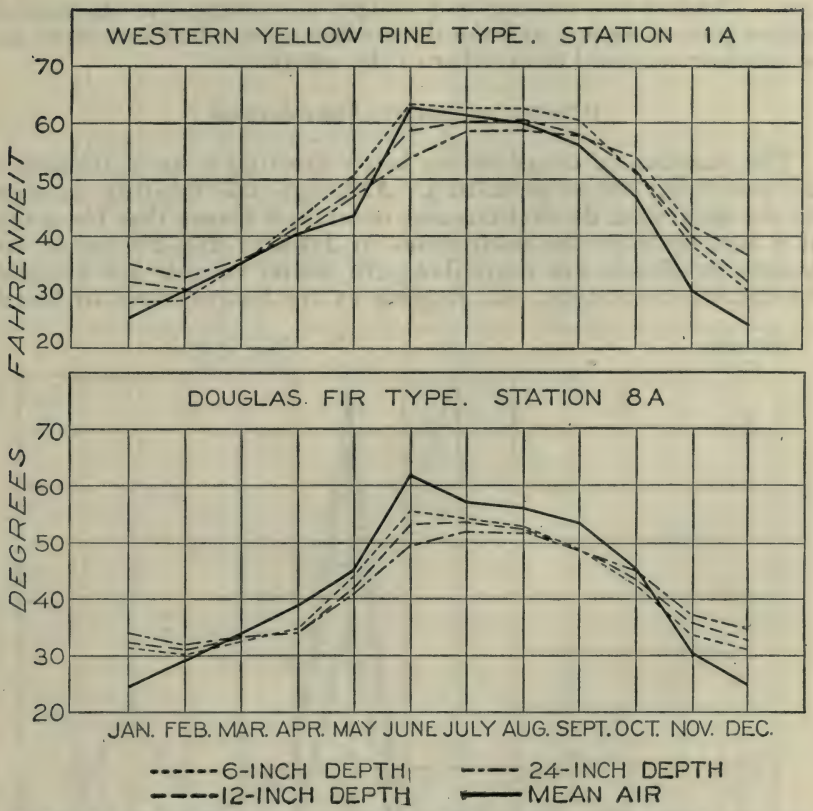

FIGURE 21.—Soil temperature at different depths in the western yellow pine and Douglas fir types, San Francisco Mountains, 1918

Making due allowance for the effects of cover and slope, it is evident that soil temperature decreases with a rise in altitude, as is shown in Table 12 and Figure 22 and especially by a comparison of the graphs for western yellow pine, Engelmann spruce, and timber

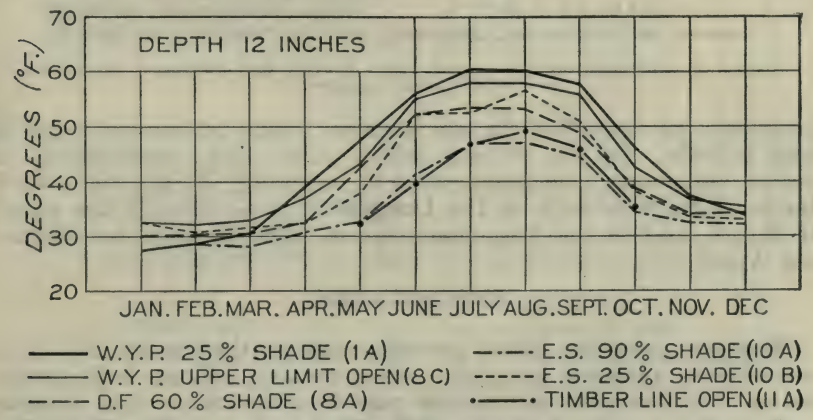

FIGURE 22.—Soil temperature in different forest types and degrees of shade, San Francisco Mountains, 1919

line. The last two stations had a slight advantage over the western yellow pine in aspect, and the timber-line station had less cover and so was more exposed than either of the others.

Duration of Freezing Temperatures

The duration of temperatures below freezing is an indication of the possibility of winterkilling. Although the monthly averages do not show what fluctuations may occur, it is known that for depths of a foot or more the fluctuations in January and February, and usually in March, are negligible. No winter records are available for the woodland type, but, judging by the temperatures in March,

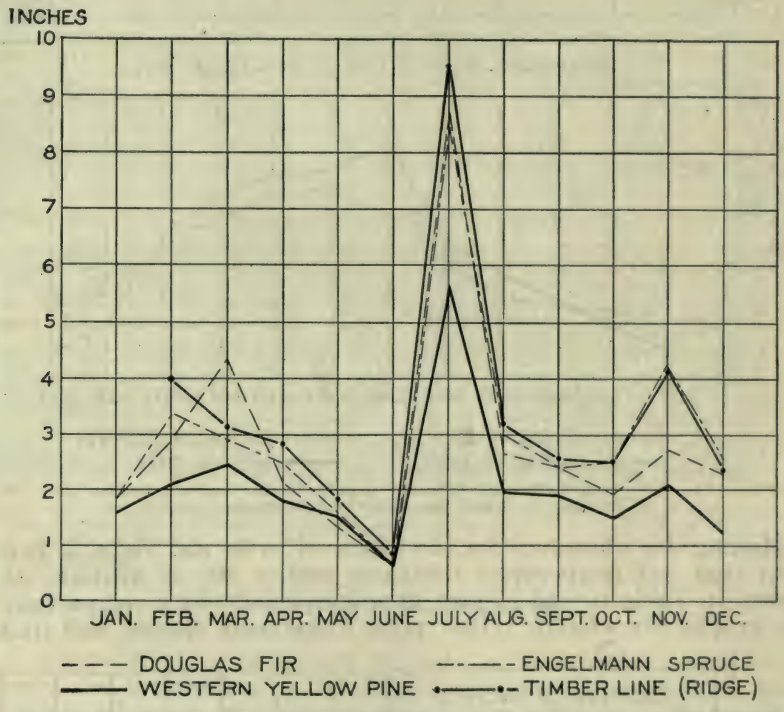

Figure 23.—Precipitation by forest types in the San Francisco Mountains, 1917–1919, inclusive

it appears unlikely that the soil remains frozen continuously during long periods. In the western yellow pine type, particularly in shaded situations, continuous records below 32° F. are the rule in January and February, in the Douglas fir type through the month of March, and in the Engelmann spruce type through both March and April.

PRECIPITATION

Moisture promotes plant growth only to the extent that it is available in adequate quantities when needed. Along with precipitation it is necessary to consider run-off, evaporation, and moisture content of the soil. Unfortunately precipitation is the only one of

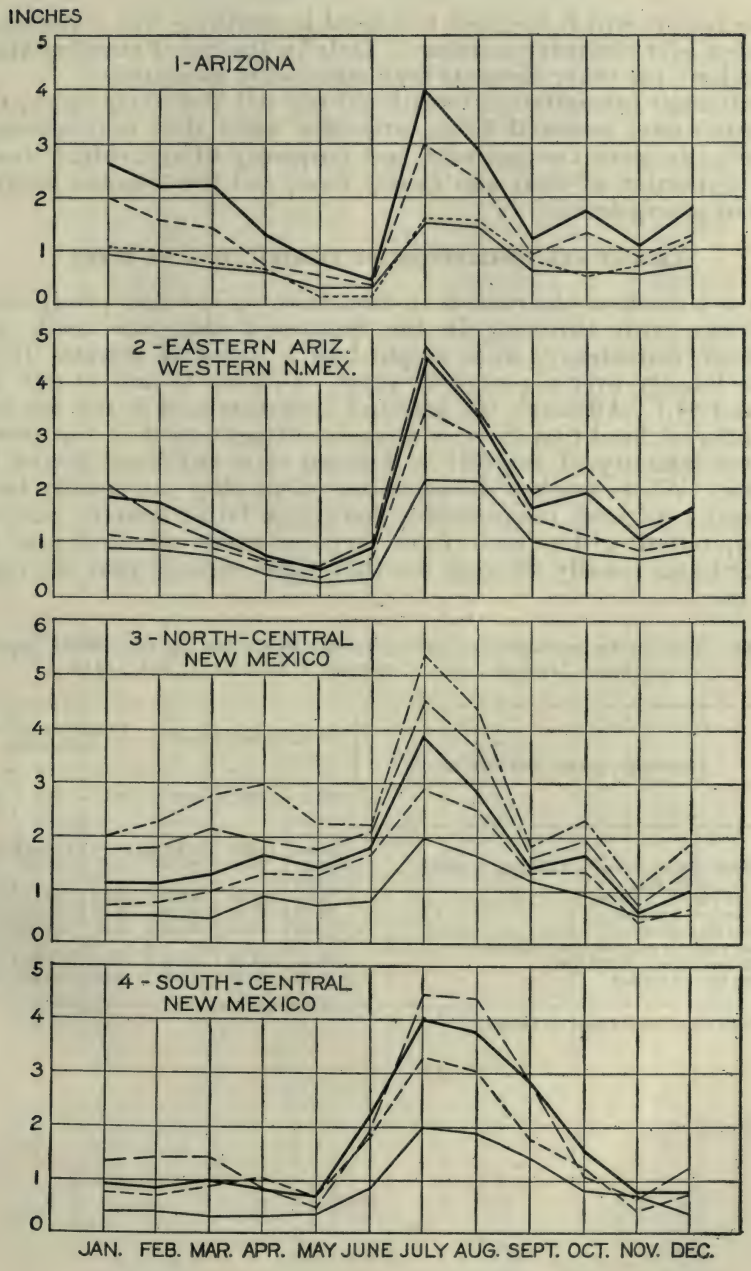

FIGURE 24.—Precipitation in different forest types grouped by regions, 1909–1921, with exceptions as noted in Table 14

47388°—31——4

these factors which has been measured in anything like a systematic manner over extensive territory. Only in the San Francisco Mountains have the other elements been adequately measured.

Although precipitation records do not tell the whole story, they give the most essential facts, especially when they are sufficiently detailed to show the intensity and frequency of individual storms, the proportion of clear and cloudy days, and the seasonal distribution of precipitation.

AMOUNT AND DISTRIBUTION OF PRECIPITATION BY TYPES

It is a common observation in mountain regions that precipitation increases with altitude. In the Southwest this rule holds with uniform consistency, when applied to a series of stations in the same locality over a period of years. (Tables 13 and 14 and figs. 23 and 24.) Although the seasonal apportionment is not the same in different localities, there is a consistent agreement in the average annual quantity of rainfall in a given type anywhere in the two States. Where marked discrepancies occur, they can usually be explained. As with temperature, there is a fairly definite range of precipitation within each forest type, stations situated near the lower limits usually showing less than those situated near the upper limits.

TABLE 13.—*Yearly variation in precipitation in inches in six forest types of northern Arizona (San Francisco Mountains), 1917–1919*

Forest type, station, and altitude	Precipitation, annual			Precipitation, May–September		
	1917	1918	1919	1917	1918	1919
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Woodland (piñon-juniper), Ash Fork, 5,100 feet	[1] 13.39	12.36	18.46	8.47	5.35	11.32
Western yellow pine:						
Fort Valley, 7,300 feet	18.18	23.58	32.03	8.79	9.15	17.47
Flagstaff, 6,900 feet	18.82	21.29	28.28	9.57	10.07	13.77
Douglas fir, 8,700 feet	23.60	35.76	43.23	13.31	12.97	21.52
Limber pine—bristlecone pine, 10,000 feet						21.29
Engelmann spruce, 10,500 feet	24.34	33.02	51.92	12.74	12.86	23.11
Timber line, 11,500 feet	28.03	37.74	52.05	14.51	15.37	23.88

[1] Cedar Glade record used for January.

TABLE 14.—*Monthly and annual precipitation by vegetational zones and regions in Arizona and New Mexico*

Region No.	Location	Stations	Length range of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total annual	May-Sept.
		Number [1]	*Years* [2]	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
DESERT																	
1	Arizona	5	19–52	1.12	1.00	0.78	0.62	0.14	0.15	1.65	1.60	0.83	0.53	0.75	1.23	10.40	4.37
GRASSLAND																	
1	Arizona	4	10–13	0.96	0.80	0.63	0.56	0.30	0.28	1.54	1.46	0.69	0.66	0.60	0.76	9.24	4.27
2	Eastern Arizona and western New Mexico	6	11–42	.91	.90	.74	.42	.27	.38	2.18	2.11	1.01	.82	.72	.90	11.36	5.95
3	North-central New Mexico	7	22–68	.52	.49	.51	.98	.81	.88	2.03	1.74	1.24	.98	.56	.58	11.32	6.70
4	South-central New Mexico	4	22–61	.44	.48	.35	.37	.40	.86	2.00	1.93	1.47	.91	.80	.49	10.50	6.66
	Average															10.60	5.90
WOODLAND (PIÑON-JUNIPER TYPE)																	
1	Arizona	9	6–13	1.97	1.58	1.42	0.75	0.55	0.37	3.09	2.35	0.97	1.42	0.91	1.32	16.70	7.33
2	Eastern Arizona and western New Mexico	14	10–48	1.14	1.03	.95	.61	.40	.72	3.55	3.04	1.47	1.20	.86	1.07	16.04	9.18
3	North-central New Mexico	8	10–13	.78	.85	1.01	1.37	1.32	1.76	2.94	2.52	1.35	1.41	.46	.72	16.49	9.89
4	South-central New Mexico	3	10–13	.80	.71	.91	1.06	.78	1.81	3.31	3.10	1.84	1.28	.49	.79	16.88	10.84
	Average															16.53	9.31
WESTERN YELLOW PINE ZONE																	
1	Arizona	3	13	2.61	2.20	2.22	1.33	0.77	0.46	4.02	2.90	1.29	1.86	1.14	1.87	22.67	9.44
2	Eastern Arizona and western New Mexico	6	9–13	1.89	1.75	1.25	.79	.56	.97	4.54	3.45	1.65	1.99	1.10	1.67	21.61	11.17
3	North-central New Mexico	11	6–13	1.18	1.14	1.32	1.72	1.44	1.85	3.90	2.91	1.44	1.71	.63	1.06	20.30	11.54
4	South-central New Mexico	4	6–13	.95	.89	1.00	.92	.77	2.20	4.00	3.86	2.89	1.62	.86	.87	20.83	13.72
	Average															21.35	11.47

TABLE 14.—*Monthly and annual precipitation by vegetational zones and regions in Arizona and New Mexico*—Continued

DOUGLAS FIR ZONE

Region No.	Location	Stations [1]	Length range of records	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	June–Sept.
		Number [1]	*Years* [2]	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1	Arizona [3]	1	3	1.85	2.96	4.39	2.12	1.38	0.66	8.83	2.68	2.38	1.94	2.77	2.24	34.20	15.93
2	Eastern Arizona and western New Mexico	2	6–10	2.10	1.48	1.07	.68	.67	1.02	4.76	3.52	1.96	2.48	1.30	1.62	22.66	11.93
3	North-central New Mexico	7	12–13	1.80	1.84	2.20	1.99	1.85	2.13	4.67	3.70	1.65	2.00	.83	1.43	26.09	14.00
4	South-central New Mexico	1	13	1.34	1.46	1.44	.90	.49	1.95	4.48	4.43	2.87	1.16	.73	1.23	22.48	14.22
	Average															26.36	14.02

ENGELMANN SPRUCE ZONE

1	Arizona [3]	1	3	1.86	3.48	2.90	2.48	1.63	0.65	8.52	3.02	2.41	2.60	4.36	2.51	36.42	16.23
3	North-central New Mexico	3	10–13	2.06	2.29	2.87	3.01	2.28	2.30	5.46	4.42	1.91	2.36	1.13	1.97	32.06	16.37
	Average															34.24	16.30

[1] In each zone and region the records from a number of stations at different altitudes have been averaged. With few exceptions, the shorter records fall within the period 1909–1921, inclusive.

[2] Minimum and maximum number of years of record.

[3] These records cover only three years, 1917–1919, and are about 9 per cent above the 1909–1921 normal.

The high altitudes of Arizona are represented only by records in the San Francisco Mountains during the 3-year period 1917–1919. Records at the control station in the western yellow pine type (Table 15) show that the average for this period was almost exactly 2 inches (9 per cent) above the average for 1909–1921. This excess was due to a very large excess in 1919, when the total was 9.41 inches (42 per cent) above the 1909–1921 average. At the control station the total for 1919 was 53 per cent above the average for 1917 and 1918, and at the Douglas fir, Engelmann spruce, and timber-line stations it was 46,[13] 81, and 58 per cent, respectively, above the 1917–18 average (Table 13). Because of the fairly consistent relationship between 1919 and the two previous years in all the forest types it seems safe to assume that the excess of 9 per cent in the western yellow pine type during the 1917–1919 period is at least a rough index of corresponding departures from normal in the other types. Accordingly, it is assumed that the average annual precipitation recorded at the Douglas fir, Engelmann spruce, and timber-line stations in region 1, as given in Table 14, should be reduced by approximately 9 per cent when compared with the 1909–1921 means given for other types and regions. This applies also to the growing-season totals, but because of the large current fluctuations which have been noted it is not considered advisable to apply correction factors to the monthly values.

TABLE 15.—*Monthly and annual precipitation at the control station (Fort Valley, Ariz.) western yellow pine zone, 1909–1925*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
1909	2.88	3.19	2.68	0.50	0.28	0.71	2.50	3.44	1.80	0	1.50	3.10	22.58
1910	2.79	.39	3.22	.50	0	.50	1.88	3.40	.41	0.59	.88	.97	15.53
1911	2.76	2.72	2.64	.22	T.	.22	5.71	2.76	3.47	2.68	.22	.69	24.09
1912	.12	.14	5.43	1.48	.55	.67	3.70	.81	.06	4.43	.25	.88	18.52
1913	.95	3.56	1.28	.09	T.	.16	2.16	4.44	1.87	1.26	1.88	1.47	19.12
1914	2.29	.86	.48	.74	.84	1.22	3.76	2.66	.89	1.84	T.	2.23	17.81
1915	3.19	2.95	.95	4.35	2.15	.35	2.92	.67	.54	.29	1.35	4.45	24.16
1916	8.57	.82	2.69	.30	.35	0	3.54	3.87	2.01	3.82	0	1.15	27.12
1917	2.98	1.43	.58	4.40	1.13	.02	5.10	.92	1.62	T.	T.	T.	18.18
1918	2.01	2.13	5.19	.31	T.	1.96	3.67	2.64	.88	.60	1.58	2.61	23.58
1919	T.	2.75	1.68	.68	3.54	T.	8.39	2.32	3.22	3.91	4.56	.98	32.03
1920	1.85	6.44	3.09	1.10	1.13	.08	2.00	2.38	.91	2.94	.97	1.02	23.91
1921	2.70	.47	1.49	1.47	2.37	.83	4.93	4.67	.19	3.13	.65	4.52	27.42
1922	4.45	1.85	3.11	1.54	1.23	1.31	1.16	2.53	1.40	1.63	2.64	1.87	24.72
1923	2.59	2.30	2.35	.93	.33	0	4.03	2.70	4.49	.32	2.66	4.39	27.09
1924	T.	.09	2.92	2.27	.09	.21	3.34	.20	3.15	1.52	.73	4.48	19.00
1925	.13	1.00	1.77	2.07	0	1.18	1.77	3.72	3.37	2.38	1.53	.11	19.03
Average	2.37	1.95	2.44	1.35	.82	.55	3.56	2.60	1.78	1.84	1.26	2.05	22.58

T.=trace.

Because it seems impractical to reduce the monthly values to a norm, the Douglas fir, Engelmann spruce, and timber-line graphs have been omitted from the Arizona series in Figure 24, and a supplementary set of graphs based entirely on 1917–1919 records is presented in Figure 23. Except for the winter and spring months, the graphs in Figure 23 are fairly harmonious when one considers the usual erratic character of precipitation. The irregularities during the winter months are probably due in part to mechanical dif-

[13] This figure is out of line because of the high precipitation recorded at the Douglas fir station in 1918. See Table 13.

ficulties in obtaining an accurate measure of snow water. Some of the most conspicuous cases, however, are accounted for by abnormal storms. An example is the high point in the Douglas fir graph in March. This is known to be the result of a tremendous local downpour of rain between March 1 and March 13, 1918, when the catch at the Douglas fir station amounted to 10.20 inches, whereas in the western yellow pine type it was 5.19 inches, and in the Engelmann spruce type it was 4.64 inches.

Table 13 shows the variations from year to year in the total annual and summer precipitation in the San Francisco Mountain region. With a few exceptions, notably in the piñon-juniper type, both the annual and the summer precipitation rise by fairly regular steps from 1917 to 1919. The increase with elevation is rapid from the piñon-juniper type to the Douglas fir type. This holds for each individual year as well as for the average and, with one exception, for the summer as well as the yearly total. Above the Douglas fir type the average rate of increase with altitude falls off, although there is still a perceptible increase up to timber line. Evidently the elevation of timber line in the San Francisco Mountains (11,500 feet) is not sufficient to record the definite decrease in precipitation that Visher (*46*) finds to be the rule above moderate heights.

The transition from grassland to woodland is accompanied by a rise in precipitation to 16 inches and more. At some stations in the lower edge of the woodland the annual catch is as low as 12 inches, whereas in the upper edge it may be as high as 20 inches. A comparison of the four regions in Table 14 shows an average variation in annual precipitation in the woodland of less than 1 inch. This, like the succeeding forest types, represents a well-defined vegetational unit in which it is reasonable to expect a rather narrow range of climatic conditions.

In the western yellow pine zone a distinct increase in precipitation is shown along with the rise in altitude over the piñon-juniper type. Of the four regions, Arizona (region 1) has the highest annual total precipitation and north-central New Mexico the lowest. The relatively low average for north-central New Mexico and for New Mexico in general may be attributed mainly to better seasonal distribution, because of greater rainfall during May and June, which would permit western yellow pine to grow with a lower annual precipitation than is required in Arizona.

Available Douglas fir records indicate a generally greater abundance of moisture than is shown by records for the western yellow pine zone. In north-central New Mexico, the only region in which there are sufficient stations and sufficiently long records to establish a good average, the Douglas fir type shows an annual excess of nearly 6 inches over the western yellow pine type for the same region. In northern Arizona, where the Douglas fir records, though at a typical station, cover only three years, the excess is 11.5 inches. In regions 2 and 4 the margin in favor of the Douglas fir type is barely more than 1 inch. Here the occurrence of Douglas fir at the higher altitudes is accounted for less by increased precipitation than by decreased temperature, which renders a given amount of precipitation more effective. At Cloudcroft, the only Douglas fir station in south-central New Mexico (region 4), the Douglas fir type is confined largely to north exposures. At higher elevations in this locality,

which probably combine higher precipitation with lower temperature, Douglas fir occupies all exposures.

The Engelmann spruce type is represented solely by three stations in north-central New Mexico and one in northern Arizona. In north-central New Mexico there is a substantial rise in precipitation as one ascends from the Douglas fir to the Engelmann spruce type. A smaller increase is indicated in the San Francisco Mountains of Arizona. In the latter region, however, the increase in precipitation in the Engelmann spruce type over that in the western yellow pine type is larger than in New Mexico.

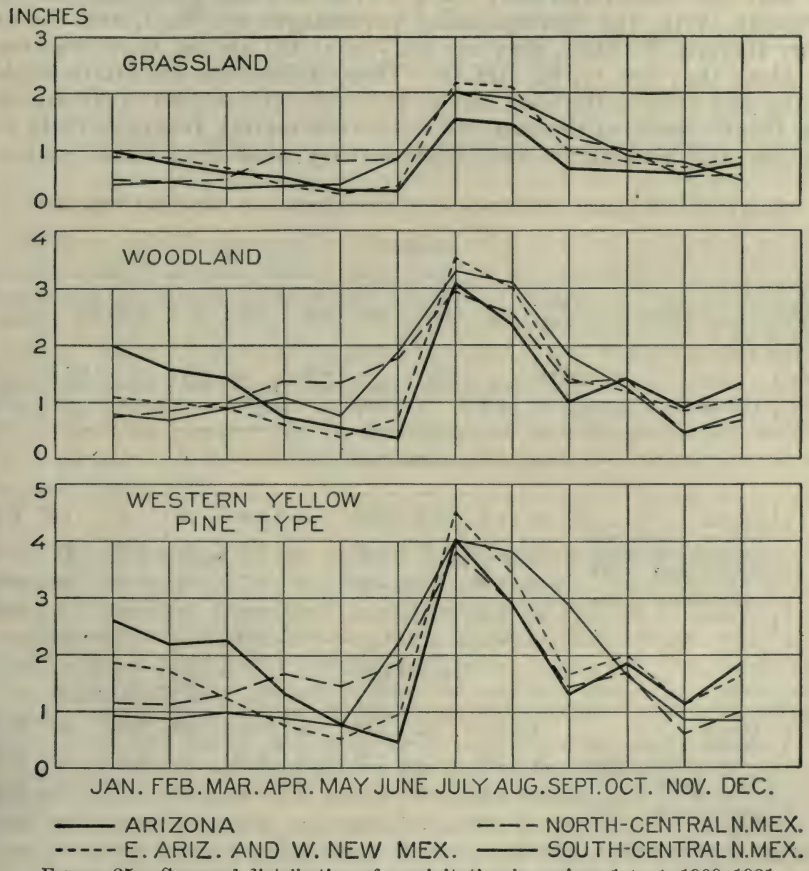

FIGURE 25.—Seasonal distribution of precipitation in regions 1 to 4, 1909–1921

Timber line, or the upper limit of the Engelmann spruce type, according to the San Francisco Mountain records (Table 13), appears to receive but slightly more precipitation than the Engelmann spruce type proper.

SEASONAL DISTRIBUTION OF PRECIPITATION

As has already been intimated, seasonal variations in precipitation are very similar at different altitudes within a given locality but are not the same when different regions are compared. This statement is amply illustrated in Figure 25 and Table 16. Arizona

and New Mexico both have a pronounced rainy season in July and August, followed by a comparatively dry autumn; New Mexico has drier winters than Arizona, but Arizona has drier weather than New Mexico during the months of April, May, and June. These differences very nearly conform to the boundary line between the two States and are manifestations of a more or less gradual trend from west to east. From the Pacific coast eastward, the winter precipitation decreases, whereas that of spring and early summer increases. At Los Angeles 78 per cent of the annual precipitation occurs between December 1 and April 1, while less than 4 per cent is recorded in May and June, and only 0.2 per cent in July and August. At Prescott, Ariz., the corresponding percentages are 39, 4, and 34; at Fort Bayard, N. Mex., they are 22, 7, and 42; and at Fort Stanton, N. Mex., they are 17, 14, and 40. These differences are attributable to the fact that at the west end of the series the storms originate on the Pacific coast, at the east end they come mainly from the Gulf of Mexico, and between the two extremes they come from either source.

TABLE 16.—*Seasonal distribution of precipitation in different regions*[1]

Region No.	Location	Stations	Nov.–Mar.		Apr.–June		July–Aug.		Sept.–Oct.		Annual
		Number	*Inches*	*Per cent*	*Inches*	*Per cent*	*Inches*	*Per cent*	*Inches*	*Per cent*	*Inches*
DESERT											
1	Arizona	5	4.88	47	0.91	9	3.25	31	1.36	13	10.40
GRASSLAND											
1	Arizona	4	3.75	41	1.14	12	3.00	32	1.35	15	9.24
2	Eastern Arizona and western New Mexico	6	4.17	37	1.07	9	4.29	38	1.83	16	11.36
3	North-central New Mexico	7	2.66	23	2.67	24	3.77	33	2.22	20	11.32
4	South-central New Mexico	4	2.56	24	1.63	16	3.93	37	2.38	23	10.50
WOODLAND											
1	Arizona	9	7.20	43	1.67	10	5.44	33	2.39	14	16.70
2	Eastern Arizona and western New Mexico	14	5.05	31	1.73	11	6.59	41	2.67	17	16.04
3	North-central New Mexico	8	3.82	23	4.45	27	5.46	33	2.76	17	16.49
4	South-central New Mexico	3	3.70	22	3.65	22	6.41	38	3.12	18	16.88
WESTERN YELLOW PINE ZONE											
1	Arizona	3	10.04	44	2.56	11	6.92	31	3.15	14	22.67
2	Eastern Arizona and western New Mexico	6	7.66	35	2.32	11	7.99	37	3.64	17	21.61
3	North-central New Mexico	11	5.33	26	5.01	25	6.81	34	3.15	15	20.30
4	South-central New Mexico	4	4.57	22	3.89	19	7.86	38	4.51	21	20.83

[1] Records, with few exceptions, cover the period 1909–1921.

TABLE 16.—*Seasonal distribution of precipitation in different regions*—Continued

DOUGLAS FIR ZONE

Region No.	Location	Stations	Nov.–Mar.		Apr.–June		July–Aug.		Sept.–Oct.		Annual
		Number	*Inches*	*Per cent*	*Inches*	*Per cent*	*Inches*	*Per cent*	*Inches*	*Per cent*	*Inches*
1	Arizona [1]	1	14.21	41	4.16	12	11.51	34	4.32	13	34.20
2	Eastern Arizona and western New Mexico	2	7.57	33	2.37	10	8.28	37	4.44	20	22.66
3	North-central New Mexico	7	8.10	31	5.97	23	8.37	32	3.65	14	26.09
4	South-central New Mexico	1	6.20	27	3.34	15	8.91	40	4.03	18	22.48
	ENGELMANN SPRUCE ZONE										
1	Arizona [1]	1	15.11	41	4.76	13	11.54	32	5.01	14	36.42
3	North-central New Mexico	3	10.32	32	7.59	24	9.88	31	4.27	13	32.06

[1] Record covers only 3 years.

A strip extending roughly 50 miles west and 100 miles east of the Arizona-New Mexico State line (region 2) constitutes a transition zone in which conditions in any particular year may approach either of the two extremes but on an average are more like those prevailing farther west. It should be borne in mind that Figures 24 and 25 represent the average distribution over a period of 13 years. Any single year may prove an exception. Thus, it happens that May and June are not always dry in Arizona, nor are they always wet in New Mexico. This subject has been discussed by the writer in an earlier paper (*33*).

RUN-OFF

It is known that of the annual precipitation a very considerable proportion runs off the surface as flood water. No data are available for a direct, quantitative comparison of run-off in the various vegetational zones, but, by applying existing knowledge regarding precipitation, soil, ground cover, and forest cover, one can not escape the conclusion that the proportion of surface run-off is generally greater at the lower than at the higher altitudes. Soil cover more than any other factor accounts for this difference.

Despite an annual rainfall in the desert and grassland of only 9 to 12 inches, floods of such proportions as to endanger life and property are by no means uncommon. Ample evidence of such floods is furnished by the numerous deep arroyos and the débris which marks the high-water line of the larger streams. These conditions are readily understood when one considers that a drought of three months or more may be followed by a rainfall of 4 or 5 inches in a few days. Add to this a scanty cover of vegetation often associated with shallow, compact soil, and it becomes evident that the lower country in the Southwest furnishes ideal conditions for excessive run-off and erosion. These naturally unfavorable conditions are rendered infinitely worse by the overgrazing which is everywhere in evidence. Where the ground is occupied by trees, brush, or grass both run-off and erosion are greatly checked.

In the piñon-juniper type the soil is well protected by vegetation when natural conditions have not been violently disturbed. But on extensive areas the natural cover has been destroyed not only by overgrazing but also by timber cutting, fire, and cultivation. Here, where precipitation is much heavier, denudation approaches that of the grassland, and run-off is great. Sheet erosion removes the surface soil, cow trails and wagon roads are cut down to bedrock, and the creeks and larger arroyos carry away the soil from entire valleys.

The western yellow pine type in its virgin state is well adapted to conserving moisture. The crown canopy breaks the force of the rain and retards the melting of snow. Observations by Jaenicke (*21*) at the Southwestern Forest and Range Experiment Station have shown that in a western yellow pine forest snow usually lies from 10 days to two weeks longer than in a neighboring treeless park. Leaf litter 2 inches deep carpets the soil around the trees, and open spaces are occupied by a luxuriant growth of grass or young pines. Under these conditions there is little danger of surface run-off and erosion; but when man introduces lumbering, grazing, and fire, the situation rapidly changes, and the ground becomes bare, the slopes gullied, and the valleys channeled.

The Douglas fir and Engelmann spruce forests are the great storage reservoirs which feed the permanent springs and streams in the Southwest. Heavy precipitation, dense cover, and porous soils combine to create ideal conditions for water supply. Relatively little cutting has been done in these types, but fire has swept enormous areas, killing nearly all the trees. Many of these burns now support a good cover of young conifers or aspen. Where the soil cover has been destroyed by logging, fire, and grazing run-off and erosion may become worse than in the lower types because the precipitation is greater and the slopes are steeper. Properly regulated logging without fire will, however, cause little permanent erosion, since the young tree growth thus protected is usually sufficient to provide adequate soil cover.

WIND, HUMIDITY, AND EVAPORATION

Water that is evaporated directly from the soil is obviously lost to vegetation. Wind and high temperature increase evaporation, and atmospheric humidity decreases it. With a knowledge of these factors, it is possible to estimate evaporation to a certain extent. Evaporation is an important factor in the Southwest because atmospheric conditions there favor extremely high water loss both from leaf surface and from the soil direct.

Although an exact determination of evaporation by the formula method requires more exact measurements of physical factors than are usually available, an experienced observer with the aid of only meager records can tell whether the evaporation in a given place is likely to be high or low. An illustration of the interrelation between wind, relative humidity, rainfall, and evaporation is furnished by Figure 26.

Other things being equal, wind movement is greatest in the high altitudes, but even here it is greatly influenced by exposure. According to Table 17 the highest movement is recorded at the ridge

station at timber line, but only 37 per cent as much is recorded at the more sheltered timber-line station on the northwest slope. The slope station, though only about 100 yards distant, is below the crest of the ridge to the north and is sheltered on the west side by a fairly dense stand of spruce. The prevailing wind in this region is from

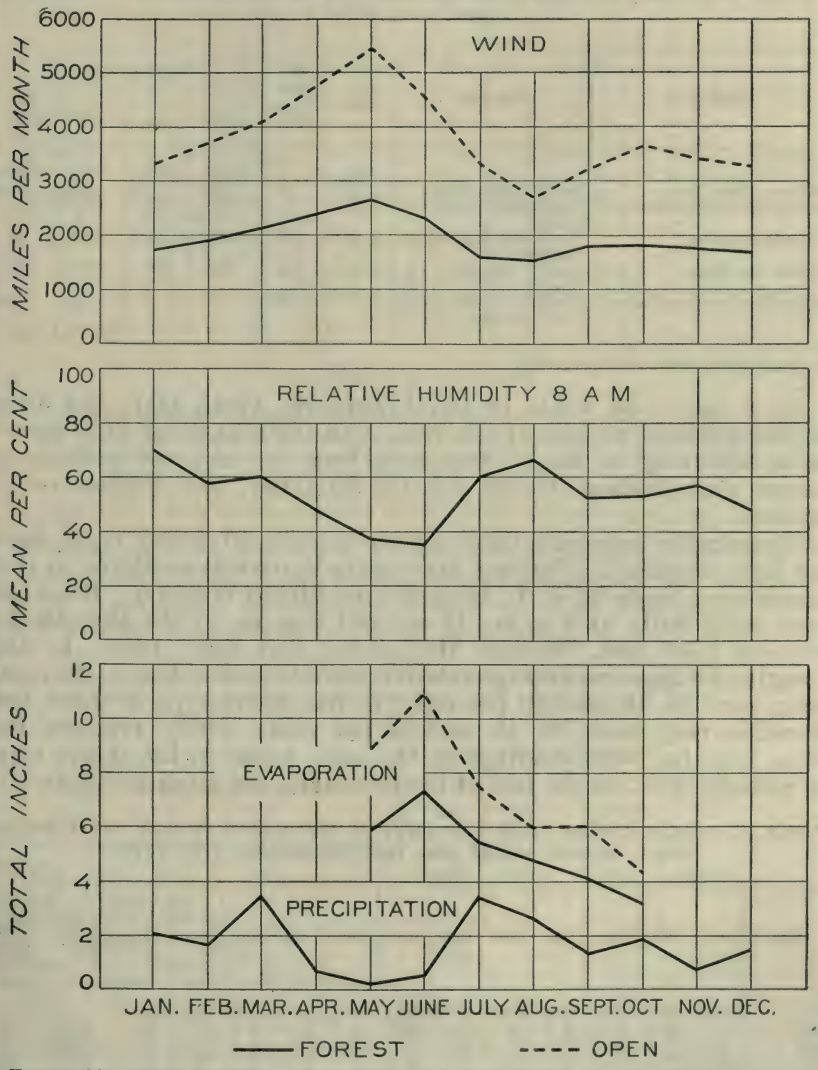

FIGURE 26.—Wind, humidity, evaporation, and precipitation at the control stations, western yellow pine type, Fort Valley, Ariz., 1909–1912, inclusive

the southwest, but at this station it is probably more nearly from the northwest. The Engelmann spruce station, also on a northwest slope, is surrounded by dense, tall timber. It records the least wind in the series and is probably typical of the better spruce and fir stands. At the limber pine-bristlecone pine station, situated only 500 feet lower but on an open southwest slope, the movement approaches

that of the timber-line ridge. Again, in the western yellow pine type the effect of forest cover is evident. This is strongly brought out in Figure 26, where conditions in the virgin forest are compared with those in an open area or park about 1 mile in diameter.

TABLE 17.—*Daily average wind movement by forest types, San Francisco Mountains, 1918* [1]

Forest type	Exposure	Altitude	Station Number	Wind movement			
				July	Aug.	Sept.	Oct.
		Feet		*Miles*	*Miles*	*Miles*	*Miles*
Western yellow pine	Level, virgin forest	7,300	1A	50.0	51.0	56.2	58.1
Limber pine–bristlecone pine	Open, steep southwest slope.	10,000	9	163.0	170.1	199.9	-------
Engelmann spruce	Northwest slope, dense forest.	10,500	10A	36.1	39.3	37.0	45.3
Timber line (ridge)	Open, exposed all sides.	11,500	11A	195.7	198.8	248.7	246.1
Timber line (northwest slope)	Ridge on south, timber on west.	11,500	11B	-------	-------	-------	91.0

[1] Anemometer 8 feet above the ground.

As is shown by Table 18 and Figure 26, April, May, and June are the windiest months of the year, with the maximum wind movement occurring in May. May and June are also the periods of lowest precipitation, lowest relative humidity, and highest evaporation.

Comparable humidity readings for a series of forest types have not been obtained. The best high-altitude records available in this region were made by E. L. Hamilton on Mount Graham. Readings were made daily at 8 a. m., 12 m., and 4 p. m. in the Douglas fir type at 8,700 feet, through May, June, and July, 1926. In the Douglas fir type the average relative humidities for May, June, and July were 50, 38, and 60 per cent; in the desert type at 2,900 feet elevation they were 26, 18, and 32 per cent. Daily averages for June, together with readings at the same hours in the desert type at Safford, Ariz., at the foot of the mountain, are given in Figure 27.

TABLE 18.—*Daily average wind movement at the control station (Fort Valley, Ariz.), western yellow pine type, by months, 1909–1919*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average for year [1]	Average for May–Sept. [1]
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*		
1909	57.7	67.4	67.6	91.1	85.3	77.9	60.3	41.5	55.5	76.9	63.5	54.5	66.6	64.1
1910	58.4	67.2	64.4	74.5	80.5	81.7	62.4	49.9	62.1	63.4	47.7	54.3	63.9	67.3
1911	57.1	66.1	54.7	79.5	90.3	74.9	47.2	48.8	51.2	60.3	68.1	54.9	62.8	62.5
1912	57.2	67.7	67.4	78.0	83.1	71.4	53.8	55.7	68.3	57.6	56.9	61.6	64.9	66.5
1913	61.4	59.2	69.4	78.1	77.2	78.5	62.6	47.5	48.4	60.3	48.6	50.0	61.8	62.8
1914	51.8	60.3	68.0	74.2	61.8	69.0	41.8	41.8	57.6	55.8	51.2	44.0	56.4	54.4
1915	55.6	58.8	64.2	50.9	64.9	71.7	40.5	49.4	58.2	51.1	53.9	50.2	55.8	56.9
1916	59.7	45.6	66.5	67.1	89.7	82.6	41.6	46.9	50.3	66.2	62.5	70.6	62.4	62.2
1917	55.1	65.2	69.6	60.9	78.2	72.4	53.9	54.1	53.8	58.5	59.4	61.2	61.6	62.5
1918	62.8	64.4	71.1	84.4	76.6	61.4	50.0	51.0	56.2	58.2	64.0	54.4	62.9	59.0
1919	53.7	68.3	65.9	72.1	66.0	67.0	42.9	42.6	46.2	56.1	62.1	57.8	58.4	52.9
Average	57.0	62.7	66.3	73.7	77.6	73.5	50.6	48.1	55.3	60.4	58.0	55.8	61.6	61.0

[1] These averages are not absolutely correct, because they give equal weight to all months regardless of the number of days.

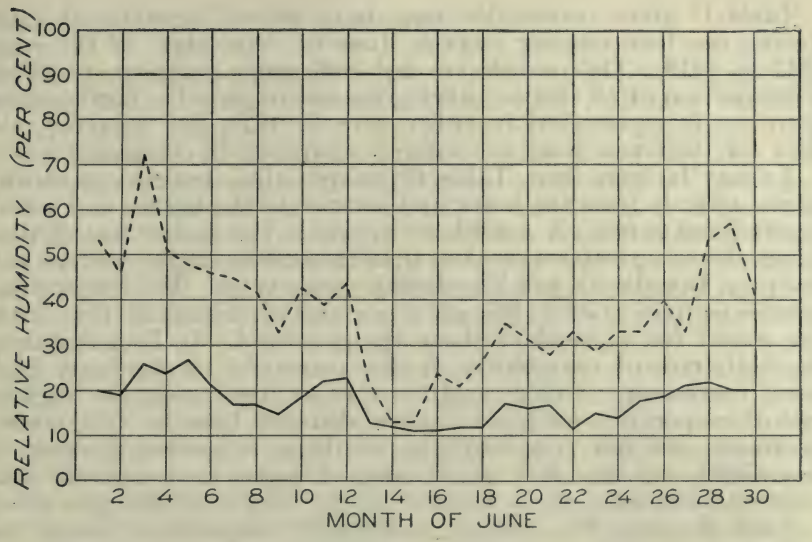

FIGURE 27.—Daily relative humidity in desert and Douglas fir type, June, 1926

Records kept at the Fort Valley forest station from May to October, 1925, reveal a low relative humidity during the month of June of 1 per cent. Records for other years show that values below 5 per cent are not uncommon during this month.

TABLE 19.—*Average evaporation and precipitation in different types in Arizona, June to September, 1918 and 1919, and average 1917–1919*

Forest type, station, and altitude	Evaporation from water surface			Precipitation	$\frac{P}{E}$ [1]
	1918	1919	Average, 1917–1919		
	Inches	*Inches*	*Inches*	*Inches*	
Grassland:					
Wilcox, Ariz.	37.31	37.29	39.62	5.97	0.151
Woodland (piñon-juniper):					
Ash Fork (open), 5,100 feet	41.95				
Western yellow pine:					
Fort Valley (forest), 7,300 feet	18.43	15.40	18.63	10.25	.550
Walnut Canyon (forest), 6,700 feet	27.12				
Douglas fir, 8,900 feet:					
Timber	15.40	11.96	15.48		
Aspen	14.69	10.77			
Average	15.04	11.36	14.86	14.55	.979
Limber pine-bristlecone pine, 10,000 feet:					
Steep southwest slope (open)		22.73			
Engelmann spruce, 10,500 feet:					
Northwest slope (forest)	6.05				
Northwest slope (open)		9.34			
Ridge (open)	16.27	14.06			
Average	11.15	11.70	10.49	14.60	1.392
Timber line, 11,500 feet:					
Ridge (open)	20.42	19.18		16.07	[2].812

[1] Precipitation divided by evaporation.
[2] Evaporation 2 years only.

Table 19 gives evaporation records in several vegetational zones during the four summer months, June to September, of the years 1917 to 1919. The records are not sufficiently complete to afford a comparison of all stations during the entire period. Each station, however, is represented in either 1918 or 1919, and therefore the data for these two years are entered separately in columns 2 and 3.

As may be seen from Table 19, evaporation decreases generally as one ascends from the lower and warmer to the higher and colder vegetational zones. A notable exception is the timber-line station, which shows a greater water loss than the stations in the western yellow pine, Douglas fir, and Engelmann spruce types. The limber pine-bristlecone pine station, though at an altitude of 10,000 feet, holds the record for all stations above the grassland. In both instances the high rate of evaporation is due primarily to extremely high wind movement. Other conditions being the same, the highest rate of evaporation occurs in the low altitudes, because of high temperatures and low humidity; on southern exposures, because of accessibility to sun and wind; and in open, as compared with forested situations, again because of the effects of sun and wind.

Table 20 gives the monthly and yearly evaporation during the summer months from 1909 through 1919 at the control station in the western yellow pine type. These records, as well as those shown in Figure 26, are from a free water surface.

TABLE 20.—*Monthly evaporation from free water surface at control station (Fort Valley, Ariz.), western yellow pine type, 1909–1919*

Year	May	June	July	August	September	October	Total, May–October
1909			4.28	3.79	3.99	3.28	
1910	6.08	8.71	5.92	5.56	4.89	4.46	35.62
1911	6.18	6.75	7.40	4.53	3.04	2.48	30.38
1912	5.20	6.46	4.61	5.16	5.06	3.92	30.41
1913	6.10	6.95	5.16	4.74	2.87	3.16	28.98
1914	5.14	5.22	3.56	4.16	4.59	1.44	24.11
1915	[1] 5.52	7.85	6.22	5.47	4.44		
1916	7.50	8.10	5.24	4.17	2.89	1.94	29.84
1917	[1] 3.41	7.52	4.43	4.00	5.10	2.60	27.06
1918	5.40	4.86	3.54	3.46	3.35	2.43	23.04
1919	4.34	6.00	2.79	3.43	3.58	1.51	21.65
Average	5.49	6.84	4.83	4.41	3.98	2.72	27.90

[1] Interpolated in part.

Investigators sometimes make use of a moisture ratio, expressing the relation between precipitation and evaporation. (Table 19, last column.) Theoretically, this ratio should afford a very good index of moisture conditions, but it can be applied only where evaporation and precipitation have been measured contemporaneously. In this study winter records of evaporation were not obtained in the higher altitudes because of the complications introduced by freezing and heavy snowfall. In order to have a comparable series it has therefore been necessary to limit the period to four months, June to September.

SOIL MOISTURE

The quantity of moisture in the soil, accurately determined, constitutes the best single expression of moisture conditions. It is the net proceeds of precipitation minus run-off and evaporation. The effectiveness of moisture in promoting plant growth depends upon what proportion escapes direct evaporation from the surface soil, upon the fertility of the soil, and upon the efficiency of the plant mechanism in storing or making use of the water it absorbs. Some plants are capable of more growth than others with a given amount of water; most plants make better use of soil moisture on fertile soil; in all cases atmospheric conditions determine the efficiency of the plants' use of water by their influence on transpiration. High temperature, high wind movement, and low atmospheric humidity favor rapid dissipation of soil moisture. High temperature, within certain limits varying with different plants, also favors rapid growth; but high wind movement and low humidity tend to retard growth and decrease the effectiveness of soil moisture in the plant not habituated to these conditions.

One of the chief obstacles in the way of employing determinations of soil moisture on a broad scale is the mechanical difficulty of obtaining representative soil samples and determining their water content. After this laborious and time-consuming task has been accomplished, there remains the complication introduced by varying wilting coefficients [14] which must be known for each soil in order to determine what proportion of the total moisture supply is available for the use of plants. The calculated moisture percentages often fail to express the true condition, either because individual soil samples are not truly typical of the site they represent or because the wilting coefficient was not based upon a typical sample.

Another consideration in comparing soil-moisture data from different sites is the density of the vegetation, since growing plants draw moisture from the soil in quantities which may far exceed the loss by direct evaporation. In the forest the reduction of soil moisture is brought about not only by the small plants directly on the spot where the sample is taken but also by the roots of trees that stand as much as 100 feet distant. This effect would be removed if the vegetation were destroyed and the invading roots cut. If the main purpose were to measure the total potential moisture supply, removing the vegetation would be the proper procedure; but this study is concerned more with the actual conditions under which the forests are growing. Therefore, samples were taken in situations which were considered to represent average root activity.

The foregoing remarks may explain some of the apparent discrepancies in the data here presented. Although these circumstances tend to detract from their value, soil moisture data are still to be rated as our best means of studying moisture conditions in relation to

[14] Wilting coefficient indicates the point to which moisture in the soil must be reduced in order to cause permanent wilting in plants. The amount above this point is termed "available moisture" or "growth water" and that below is termed "nonavailable." The last term is not strictly accurate because plants may continue to draw water from the soil after permanent wilting has taken place, although the amount is too small to sustain life.

the growth of plants. The data here presented are confined to the San Francisco Mountains; it may be assumed, however, that they are indicative of moisture conditions in other regions under similar conditions of rainfall, soil, and cover.

COMPARISON BETWEEN FOREST TYPES

Figures 28 and 29 bring out the soil-moisture relations between the several forest types of the San Francisco Mountains, as recorded in 1918 and 1919. It should be noted that the precipitation graphs trace the readings of the month just preceding. In neither of these years was precipitation typical of the region. In 1918 the total was about normal, but the summer rains began in the middle of June, whereas usually they begin anywhere from the first to the middle of July. In 1919, heavy rainfall extending over nearly two weeks in the last half of May forestalled the usual June drought. In both these years the distribution during April, May, and June was more typical of New Mexico and Colorado than of Arizona. Soil samples were also taken during 1920, but only in the western yellow pine type. The rainfall during April, May, and June of this year proved to be fairly typical, but the summer rains were below normal.

Soil moisture determinations at a depth of 1 or 2 inches (fig. 29) show the usual sharp fluctuations characteristic of surface conditions. In most years the available moisture would have been a minus quantity, or below wilting coefficient, throughout the month of June in the western yellow pine type. As it was, the zero line was reached only toward the end of the month in the western yellow pine and not at all in the Douglas fir and Engelmann spruce. The high records in July and August are significant in relation to germination, which usually takes place during these months. In only one instance has western yellow pine been known to germinate in May or June. This was in 1919, when the heavy rainfall in May promoted abundant germination and enabled a good proportion of the seedlings to live through June until the arrival of the July rains. Even in that year, however, most of the western yellow pine seeds lay dormant until daily showers in July provided ideal conditions for growth. In the Douglas fir and Engelmann spruce types seedlings sometimes appear in June but most commonly do not come up until July.

Soil samples taken at depths of 6, 12, and 24 inches represent the strata in which nearly all the roots occur. Western yellow pine and Douglas fir send a few roots down to 4 feet, or even deeper, depending upon the permeability of the soil, but the great mass of feeders lies within 2 feet of the surface. The roots of Engelmann spruce and its associates go very little below 1 foot. The shallow rooting of western yellow pine in the vicinity of the San Francisco Mountains, as compared with its habit in some other localities, is believed to be due to heavy subsoil. In one place where the roots stopped on reaching hardpan at a depth of about 2 feet, a crevice extending down to a depth of 4 feet and filled with sand and gravel contained a dense mat of roots. The shallow rooting of Engelmann spruce and its associates in this region is not due to impermeable soil, for the soil is exceedingly porous. It may be inherent in these species or be due to the fact that the surface foot of soil is

usually well supplied with moisture. Soil temperature may also be a factor.

According to Figures 28 and 29, no serious drought occurred below the surface layer in either year, except in the piñon-juniper type in 1918. In 1920, however, the available moisture at the 6-inch

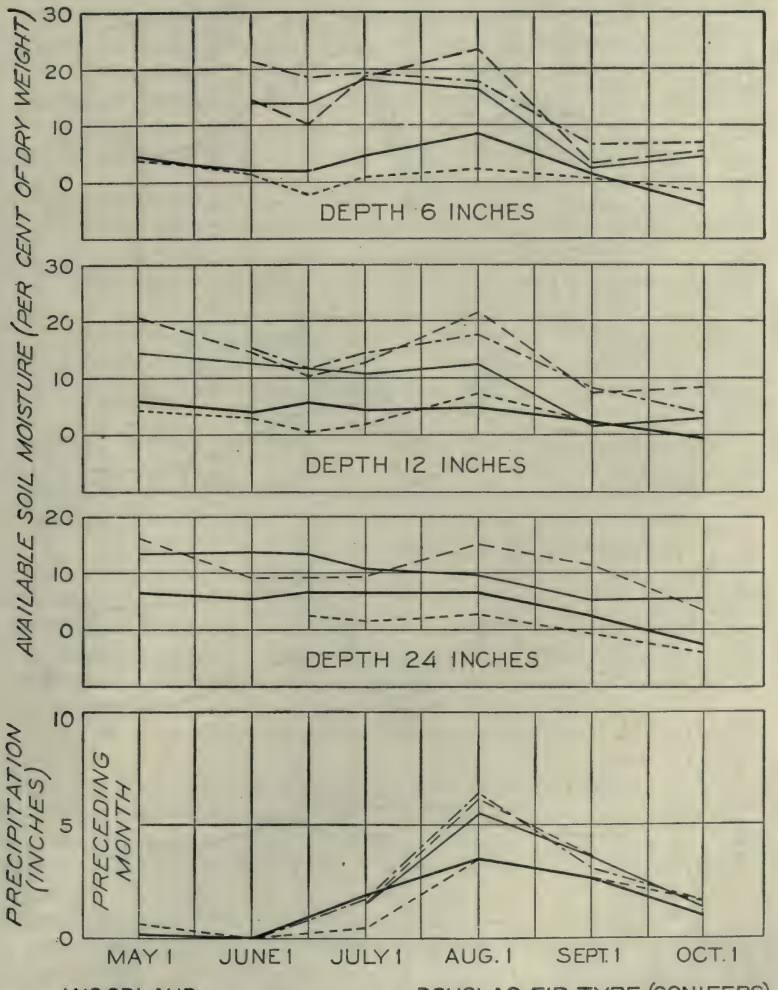

FIGURE 28.—Available soil moisture in different forest types, San Francisco Mountains, 1918

depth fell to the zero line in the western yellow pine type in June and again in September. Previous records in the western yellow pine have shown that for depths of 12 inches or less, complete or nearly complete exhaustion of growth water may usually be expected in the latter part of June. All information at hand indicates that

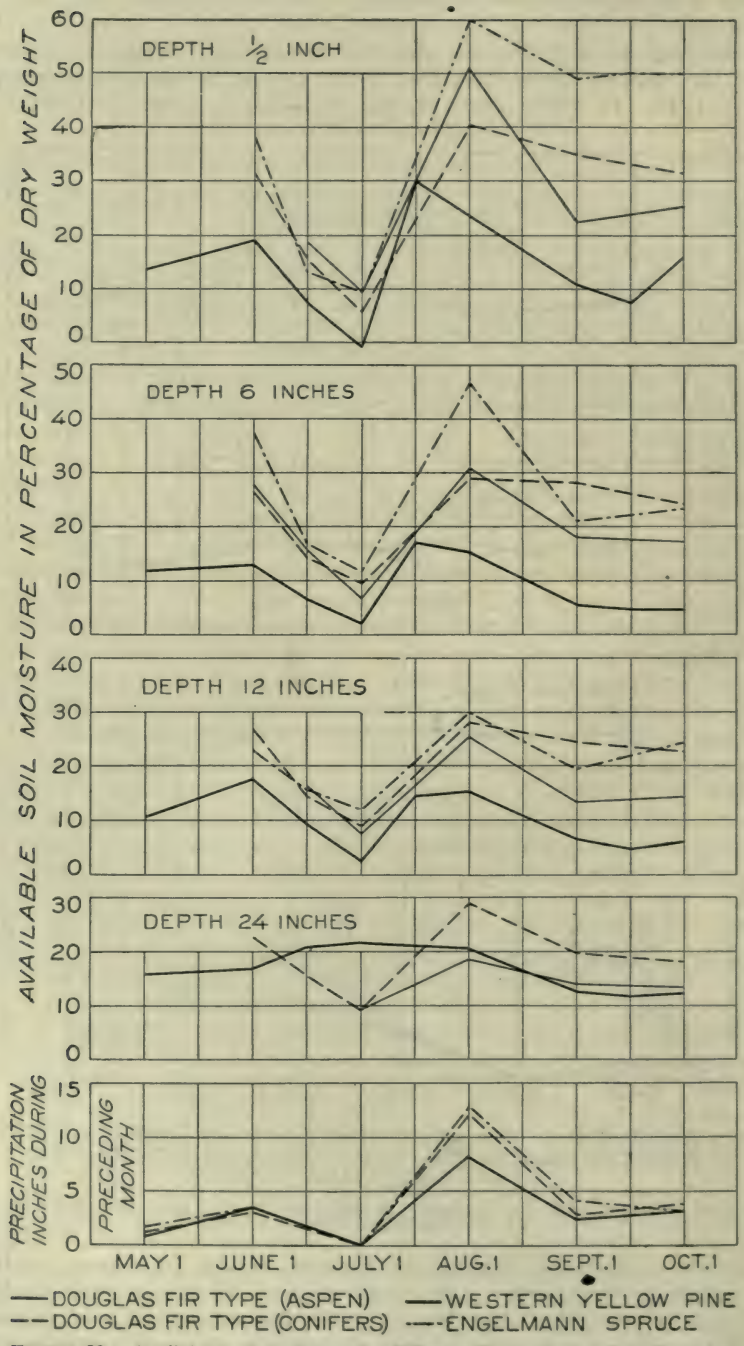

FIGURE 29.—Available soil moisture in different forest types, San Francisco Mountains, 1919

far more extended depletion is the rule in the piñon-juniper type. In the Douglas fir and Engelmann spruce types, droughts during the main growing season must be exceedingly rare. In the spruce type, the greatest depression is likely to come late in the summer when growth is at its height, as in 1918. In 1919, a depression was noticeable in the latter part of August but, because of the abnormally heavy rainfall in this type, amounting to 7.09 inches more for July and August than in the preceding year, was less pronounced than in 1918. When the tremendous water consumption of a dense stand of growing spruce or fir is considered, it is conceivable that the moisture supply may be taxed even with a monthly rainfall of nearly 5 inches. A similar late-summer depression may occur in western yellow pine stands in years of average or deficient rainfall.

At a depth of 24 or more inches moisture sufficient to sustain plant growth is usually to be found through the main growing season in all forest types, except woodland. This supply of moisture is attributed to the heavy winter precipitation in the higher types. On several occasions excavations in the western yellow pine type at the Fort Valley station have shown the soil to be well saturated in the spring of the year to a depth of 6 feet. In the woodland zone, however, nearly dry soil has been found in May at a depth of 2 feet. Above the western yellow pine type snow persists so late that the dry period in the late spring and early summer usually experienced in lower altitudes is scarcely perceptible. This is especially true of the Engelmann spruce type, where the snow lies well into June.

VARIATIONS WITHIN FOREST TYPES

Moisture determinations have been made in treeless openings of the western yellow pine type and woodland, in aspen thickets of the Douglas fir type, and in openings in spruce stands, with a view to ascertaining whether soil moisture is a factor in creating these openings.

Woodland Parks

Samples representing the typical soil of piñon-juniper woods were taken on a rocky upland situation, and those representing the park were taken in a sparsely wooded valley about 50 yards distant. Limestone is the prevailing rock in this locality. The upland soil is generally so stony that holes a foot deep can be dug only with great difficulty. The vegetation in addition to trees consists of a sparse growth of grama grass, sage, and various other shrubs. In the valleys the soil is practically free of stones. Grama grass covers about one-half of the ground surface. Samples at 6-inch and 12-inch depths in 1918 indicated a consistently lower available moisture content in the valley during the driest periods. A few samples taken in 1918 showed the same relation.

Western Yellow Pine Parks

In the western yellow pine type comparisons were made between the forest, the edge of the forest, and a large park or valley devoid of trees. In the forest, the samples were taken on a level site within an area reached by the roots of large trees. The soil here is stony

clay loam derived from basalt and typical of the western yellow pine forest in this locality. The transition between forest and park is marked at this point by a rather abrupt slope to the southeast, descending about 25 feet from the forest to the floor of the valley. Samples were taken midway of the slope, where the soil is very gravelly but comparatively free from large stones. Roots from neighboring trees and saplings reach the area, and seedlings from 7 to 10 years old are abundant. The valley soil is free from stones but contains a moderate proportion of sand and gravel. The sticky clay subsoil characteristic of the forest does not occur here. Over considerable portions of the valley a hardpan of cemented gravel

FIGURE 30.—Available soil moisture in forest and park, western yellow pine type, 1920, depth 12 inches

and cinders is found 12 to 18 inches below the surface, but this layer was not encountered down to 2 feet at the point where the samples were taken.

In comparing the wilting coefficients on the three sites (Table 21) it will be seen that the highest values are those of the forest and the lowest those of the slope, values in the park being intermediate. The topography would lead one to expect the heaviest soil in the park, but extremely heavy soils are found only in the depressions.

The park area where the samples were taken bears a grama-grass sod of about 0.4 density and scattered plants of tall larkspur and a few other herbs. This vegetation remains relatively inactive until the arrival of the summer rains in July, when, if the rains are abundant, it becomes luxuriant.

In 1919, a year of abnormally heavy rainfall, available moisture was highest in the forest but only slightly lower in the park. The slope between forest and park has much the lowest values during periods of abundant rainfall, but when a drought of several weeks occurs the value here tends to hold up better than in other situations. This relationship was strongly brought out in 1920, which was a year of subnormal rainfall through the growing season. (Fig. 30.) The slope had the highest values in June and early July, particularly at a depth of 6 inches. Neither the slope nor the forest soil approached dangerously near the wilting point, but the park soil was below the wilting point during a large portion of the summer. This study points toward unfavorable moisture conditions as an important and perhaps the dominant factor in explaining the absence of a western yellow pine forest in the parks.

TABLE 21.—*Available soil moisture in percentage of dry weight at different depths by forest types, San Francisco Mountains, on different dates, 1918–1920*

Depth and forest type	Station No.	Wilting coefficient	1918 RECORDS May 1	June 1	June 15	July 1	Aug. 1	Sept. 1	Oct 1
6 inches:									
Piñon-juniper—			*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Stony mesa	4A	8.1	3.9	1.9	−2.0	1.1	2.6	0.7	−1.4
Valley	4B	10.7	.6	1.6	−2.0	−1.3	4.4	−3.5	−3.6
Western yellow pine	1A	12.4	4.3	1.5	1.8	4.7	8.3	1.2	−4.1
Douglas fir—									
Conifers	8A	8.0	------	14.4	9.8	18.5	23.7	3.3	5.5
Aspen	8B	6.5	------	14.9	13.8	18.0	16.5	2.1	4.4
Limber pine-bristlecone pine—									
Open southwest slope	9	6.5	------	4.4	2.4	------	------	------	5.6
Engelmann spruce—									
Forest (northwest slope)	10A	5.7	Snow	21.1	18.3	19.4	17.8	6.6	7.0
Opening (ridge)	10B	7.8	------	24.8	12.1	23.6	18.7	3.7	12.0
12 inches:									
Piñon-juniper—									
Stony mesa	4A	8.4	4.2	2.9	.6	1.8	7.1	2.1	−.4
Valley	4B	12.3	2.3	1.4	−2.0	.6	4.4	------	−6.1
Western yellow pine	1A	12.8	5.9	3.8	5.7	4.4	5.1	2.1	−.5
Douglas fir—									
Conifers	8A	7.7	20.4	14.7	10.2	12.5	21.8	7.6	8.6
Aspen	8B	7.1	14.4	13.0	11.3	10.8	12.7	1.7	3.2
Limber pine-bristlecone pine—									
Open southwest slope	9	7.0	6.2	3.3	5.9	7.8	12.2	1.3	7.2
Engelmann spruce—									
Forest (northwest slope)	10A	7.5	Snow	15.0	11.6	14.2	17.8	8.1	3.8
Opening (ridge)	10B	7.7	26.5	21.6	22.8	11.7	19.8	14.2	7.7
24 inches:									
Piñon-juniper—									
Valley	4B	10.6	------	------	2.2	1.5	2.9	−.8	−4.0
Western yellow pine	1A	15.1	6.8	5.4	6.5	6.3	6.5	2.6	−2.5
Douglas fir—									
Conifers	8A	6.5	16.6	9.3	9.8	9.3	14.9	11.2	3.6
Aspen	8B	5.5	13.7	13.9	13.8	10.5	9.7	5.2	5.6

1919 RECORDS

Depth and forest type	Station No.	Wilting coefficient	May 1	June 1	June 15	July 1	July 15	Aug. 1	Sept. 1	Sept. 15	Oct. 1
Surface one-half inch underneath litter:											
Western yellow pine—		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
Forest	1A	8.3	14.3	19.2	7.4	−0.8	31.2	24.3	10.4	7.9	14.7
Edge of forest	1A	7.7	------	12.7	------	------	14.3	13.4	6.0	------	------
Park	1A	8.0	------	19.0	------	------	22.8	29.0	26.8	------	------
Douglas fir—											
Conifers	8A	7.4	------	31.6	15.6	6.0	------	41.0	35.1	------	32.1
Aspen	8B	8.7	------	------	18.8	9.0	------	51.0	22.4	------	26.2
Engelmann spruce—											
Forest (northwest slope)	10A	8.9	------	39.4	13.9	8.9	------	60.6	49.4	------	50.6
Opening (northwest slope)	10A	6.6	------	32.1	8.3	13.5	------	61.4	21.7	------	34.8
Forest (ridge)	10A	12.3	------	------	14.3	7.2	------	56.4	54.4	------	36.8
Opening (ridge)	10B	7.2	------	53.9	21.8	21.0	------	34.9	41.5	------	38.8
6 inches:											
Western yellow pine—											
Forest	1A	13.5	11.9	12.8	6.5	2.2	17.0	15.3	5.4	4.4	4.4
Edge of forest	1A	9.0	11.6	12.0	5.3	3.2	16.1	15.7	------	------	------
Park	1A	10.8	12.0	15.8	6.1	−1.0	20.0	19.3	6.4	------	------
Douglas fir—											
Conifers	8A	8.0	------	26.6	14.4	9.4	------	29.0	28.2	------	24.0
Aspen	8B	6.5	------	28.0	15.9	7.0	------	30.9	18.2	------	17.2
Engelmann spruce—											
Forest (northwest slope)	10A	5.7	------	38.3	16.8	11.6	------	47.5	20.9	------	23.3
Opening (northwest slope)	10A	7.2	------	19.3	12.0	9.1	------	36.4	28.8	------	45.2
Forest (ridge)	10A	8.7	------	------	20.6	10.8	------	41.5	29.5	------	31.1
Opening (ridge)	10B	7.8	------	33.5	21.9	20.3	------	36.4	30.6	------	28.8
12 inches:											
Western yellow pine—											
Forest	1A	16.0	10.8	17.6	9.0	2.2	14.5	15.2	6.1	4.9	5.9
Edge of forest	1A	8.8	------	11.8	7.4	4.5	14.1	14.0	5.5	------	------
Park	1A	11.4	11.1	13.0	8.6	1.8	16.1	16.0	9.1	------	------
Douglas fir—											
Conifers	8A	7.7	------	27.1	14.9	8.7	------	28.2	24.6	------	22.7
Aspen	8B	7.1	------	------	16.3	7.8	------	25.6	13.7	------	14.4
Engelmann spruce—											
Forest (northwest slope)	10A	7.5	------	23.0	15.5	11.8	------	30.1	19.7	------	23.9
Opening (northwest slope)	10A	7.4	------	29.4	12.2	10.5	------	27.5	22.2	------	19.2
Forest (ridge)	10A	7.8	------	------	17.1	14.1	------	25.2	24.7	------	23.5
Opening (ridge)	10B	7.7	------	28.2	21.3	20.3	------	25.1	31.7	------	28.9
24 inches:											
Western yellow pine—											
Forest	1A	16.6	15.3	16.2	20.4	21.3	20.7	20.3	12.4	11.4	12.0
Edge of forest	1A	8.8	------	13.0	7.2	9.6	14.2	14.9	10.3	------	------
Park	1A	10.2	4.9	10.8	11.0	9.9	17.1	17.4	13.3	------	------
Douglas fir—											
Conifers	8A	6.5	------	23.0	15.0	9.3	------	29.2	19.4	------	18.4
Aspen	8B	5.5	------	------	14.9	9.3	------	18.8	13.4	------	13.1
Engelmann spruce—											
Forest (northwest slope)	10A	6.2	------	20.0	------	------	------	10.6	------	------	------
Opening (northwest slope)	10A	4.4	------	22.1	------	------	------	20.8	------	------	------
Forest (ridge)	10A	8.3	------	------	------	------	------	21.2	------	------	------
Opening (ridge)	10B	9.3	------	22.1	------	------	------	23.5	------	------	------

1920 RECORDS

Depth and forest type	Station No.	Wilting coefficient	May 17	June 4	June 19	July 6	July 14	Aug. 9	Sept. 3	Oct. 6
6 inches:										
Western yellow pine—		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
Forest	1A	13.1	7.0	4.5	1.8	------	2.9	6.4	0.1	0.6
Edge of forest	1A	9.0	8.8	7.9	3.1	1.2	1.8	4.8	1.8	2.2
Park	1A	10.8	10.8	6.9	−.4	−.7	−3.2	.6	−.5	−.8
12 inches:										
Western yellow pine—										
Forest	1A	15.4	9.2	8.3	5.0	2.9	7.0	4.1	3.1	5.0
Edge of forest	1A	8.8	10.2	8.4	5.4	2.8	3.8	2.9	2.6	3.0
Park	1A	11.4	11.3	10.1	2.5	.2	−1.2	−1.4	−.2	−.6

Western yellow pine seedlings from 7 to 12 years old are scattered through a large portion of this park. Whether they will persist to tree size remains to be seen, since where hardpan occurs within 2 feet of the surface they will not be able to reach the lower soil strata upon which they ordinarily depend to tide them over dry periods. Plantations in the park have made a promising start but have failed after two or three years, due mainly to winterkilling.

Aspen Areas

The aspen stands of the Douglas fir zone and the lower portion of the Engelmann spruce zone present a problem somewhat different from that of the parks. Here is found direct evidence of the former existence of a conifer forest which was destroyed by fire. In many places where seed trees remain the conifers are coming back satisfactorily. Elsewhere, however, the conifers are returning, if at all, so slowly as to raise a doubt whether all the aspen areas are truly suited to a conifer forest. Climate is clearly not a controlling factor. The reactions to differences in topography are not consistent. Though aspen attains greatest size in the depressions, it is abundant and often grows to good size on steep slopes.

In the present study soil samples were taken in a Douglas fir stand on a northwest slope at the Douglas fir weather station and also in a stand of aspen on a nearly level bench about 50 yards distant. Evaporation and soil temperature are practically the same at the two stations. The only conspicuous differences in the soils of the two sites are a greater abundance of bowlders in the Douglas fir forest and a darker color in the surface layers of the aspen soil. The wilting coefficients at depths of 6, 12, and 24 inches are slightly lower in the aspen, contrary to what one would expect if the soil were unfavorable to conifers. A few conifers are scattered over the area, though the number is not commensurate with the quantity of seed available. Experimental plantations of Douglas fir and blue spruce on the aspen site have given encouraging results at the end of seven years. Herbaceous cover consisting of such plants as vetch, geranium, columbine, and bromegrass grows luxuriantly in the aspen but rather sparingly among the conifers.

Soil samples taken in 1918 and 1919 (Table 21) indicated a lower percentage of available moisture in the aspen stand than in the conifer; yet there is no suggestion of drought. The differences noted may be attributed rather to greater water consumption of the aspen and the rich herbaceous growth beneath it than to inherent differences in characteristics of the soil. The conclusion, therefore, is that, as far as soil moisture and other soil conditions are concerned, the aspen-covered area is practically as favorable for growth of conifers as are the areas now occupied by conifer stands. This conclusion applies to all the benches and slopes but may not apply to the lower valley lands.

Engelmann Spruce Openings

Openings from 50 to 75 feet wide, in which young growth, if present at all, is generally inadequate, are rather common in mature Engelmann spruce stands. Usually nothing about the topography

or external appearance of the soil in the openings suggests conditions different from those prevailing in the forest proper. Whatever may be their origin, the fact that evidently for 50 years or more they have not been restocking gives rise to speculation, especially as in many places the remains of stumps or tree trunks tell of former productiveness and the roots of surrounding trees now extend well into the openings.

In 1918 and 1919 the moisture content at various depths in openings on a steep northwest slope and on a ridge were compared with similar measurements in adjacent spruce stands. (Table 21.) Reproduction was lacking in both places. The moisture percentages in the opening on the northwest slope tended to run somewhat below those of the timbered area, which in turn were exceeded by those of the ridge opening. In no place, however, were the moisture values dangerously low. Beds sown to Engelmann spruce and bristlecone pine in the ridge opening in 1918 and again in 1919 have produced thrifty seedlings of both species. Engelmann spruce sown in the northwest-slope opening germinated, but the seedlings died after two years. Spruce seedlings of natural origin have shared the same fate, with the exception of a few on rotten logs.[15] The probable explanation of poor survival in similar small openings on north exposures at high elevations is deficient heat, which may manifest itself through low activity of soil organisms, as found by Hesselman (*20*) in Sweden, or through retardation of plant functions dependent upon heat energy. On sunny exposures the critical factor is probably surface moisture as related to germination, because here both Engelmann spruce and bristlecone pine seedlings, once past the initial stages of establishment, grow vigorously.

SOILS

Several phases of the subject of soils have been discussed in connection with climate. Thus, soil temperature has been treated along with air temperature; soil moisture has been discussed in its relation to precipitation, evaporation, and humidity; and permeability is referred to repeatedly as a primary factor in depth and development of roots.

GEOLOGIC ORIGIN

In the region of the San Francisco Mountains, the soils are derived mainly from lavas of various forms. In addition to the San Francisco crater, there are many smaller volcanic cones, all of which have contributed material in the form of lava flows, fragmental blocks, or cinders (*37*). On San Francisco Peak, which appears to be typical of the higher portion of the San Francisco Plateau, the rocks above 8,000 feet are largely of the acidic or subbasic volcanic type consisting of andesite, latite, dacite, and rhyolite. The last,

[15] Survival on rotten logs has also been pointed out by Lowdermilk (*27*) in the Northwest. He attributes this to favorable surface moisture. In this region, however, moisture is not the solution, since here the soil is almost continually moist on as well as beneath the surface, and, as has been pointed out, the seedlings survive for two or three years. It is more likely that the impetus given by the logs is of a chemical nature. Whatever this benefit may be, the unthriftiness of the seedlings indicates that it is inadequate.

which is the most highly acidic, occupies only small areas. In contrast to the acidic rocks are the basic basaltic rocks at lower elevations. Massive basalts underlie the surface 10 to 15 miles or more from the foot of the mountain, overlying the earlier sedimentary formations. Of the sedimentary formations, the most extensive is the Kaibab (Pennsylvanian), which consists mainly of a grayish, more or less arenaceous limestone containing magnesium in places and nodules of chert commonly. Thin layers of sandstone occur with the limestone in places, often almost completely distintegrated but traceable in the form of sandy material. Underneath the Kaibab formation lies the grayish or yellowish Coconino sandstone. This appears only in canyons or on the rim of the plateau and therefore is unimportant in relation to the forest soils of this region. The Moencopi formation consists of reddish sandstone or reddish, sandy shale. It appears on the surface only over small areas.

In addition to volcanic and sedimentary formations similar to those here mentioned granite occurs over a large part of the forest regions of Arizona and New Mexico. No attempt is made here to describe the geologic formations of the entire region, partly because the information is not available and partly because such a description is not considered necessary to this investigation. Although the geologic source of a soil may be of great importance, other factors, such as topography and climate, are of equal or greater importance. For this region, a map showing the geologic origin of the soils would have no great significance in a study of forest types unless correlated with an equally intensive study of other factors. Students of the soil problem are coming more and more to the conclusion that a classification of soils with reference to growth possibilities must be based on the actual condition and composition of the soil itself. This includes both chemical and physical conditions—the thickness of the soil as a whole and of its separate horizons, its fertility, moisture relationships, penetrability, reaction, and the amount and stage of humification of organic matter—all of which are determined primarily by climate, with geology as a modifying factor.

CHEMICAL COMPOSITION

The chemical composition of forest soils is important but has been studied in only a fragmentary manner, owing to its complexity and the difficulty of performing adequate analyses in the course of ordinary forest investigations. A large number of samples would be required to represent a single soil type in one locality. Moreover, even if adequate analyses were available, the knowledge to interpret correctly their significance in relation to the growth of various forest trees is still lacking. Chemistry of forest soils offers an important field for further experimental research.

As has been pointed out, chemical composition is but one of the several factors involved in the productive capacity of soils. Not only are other factors important, but they may react upon the chemical condition. Temperature and precipitation in a region of such great extremes as the Southwest usually determine both the kind and the total amount of vegetation, and this, in turn, determines the

amount of organic matter, which in addition to influencing texture is the main source of nitrogen.

The ability of soil organisms to live and function is greatly influenced by temperature and moisture. In very cold climates, especially if the soil is poorly aerated, organic matter is not completely converted into available nitrates because conditions are not suitable for proper bacterial action. In hot, dry climates organic matter near the surface of the soil may be lost by chemical oxidation or slow burning. Undoubtedly this is the fate of much of the vegetable matter deposited on the ground surface in zones below the Douglas fir type.

Precipitation directly affects the soluble salts in the soil or in the parent rocks by leaching them out of the surface layers and either carrying them away or depositing them in lower soil horizons. In humid climates there is often a deficiency of soluble salts, due to excessive leaching. In semiarid climates these salts are usually abundant, but they may be deposited in excess in layers a few inches below the surface. In undrained flats or basins receiving the drainage from semiarid lands, salts or alkali often accumulates to such an extent as to be harmful to vegetation.

Chemical analyses by the Bureau of Chemistry and Soils of samples in the various forest types from the western yellow pine up to the alpine type are given in Table 22. Perhaps the most significant difference is in the nitrogen content, which increases irregularly with rising altitudes up to timber line. The types above western yellow pine also show a rise in calcium oxide.[16] The report on these analyses by the Bureau of Chemistry and Soils states that all the samples are approximately neutral in reaction and contain no excess of soluble salts. Local tests of alkalinity and acidity, by the Wherry method, of another set of samples including grassland and piñon-juniper soils are given in Table 23. These show slight alkalinity in the grassland and piñon-juniper types, the latter including both limestone and basalt; practically a neutral reaction in the western yellow pine type on both basalt and cinders; and slight acidity in the Douglas fir, Engelmann spruce, and alpine types. In view of the fact that both the basaltic and the limestone soils in the western yellow pine type are neutral, the alkalinity of the soils derived from these rocks in the woodlands and in the grassland should not be attributed to excessive alkaline characteristics of the rocks in the lower altitudes but rather to low precipitation which may cause an accumulation of soluble salts near the surface instead of washing them away or carrying them into the deeper strata. The slight acidity of the soils above the western yellow pine type might be attributed to the fact that they are derived from rocks which normally have an acid reaction; but more likely it is due to the presence of quantities of organic matter not adequately decomposed because of low temperatures in the high altitudes.

[16] According to Cajander (8), investigations in Finland have shown a strong correlation between site quality and the presence of calcium oxide and nitrates. In both Scotch pine and birch stands the highest increment is found on soils rich in these compounds. Potassium oxide shows a low correlation with increment, and phosphoric acid none at all.

TABLE 22.—*Chemical analyses*[1] *of soils in different forest types of the San Francisco mountain region*

Forest type and soil origin	Depth	Lime (CaO)	Potash (K_2O)	Phosphoric acid (P_2O_5)	Nitrogen (N)
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Western yellow pine bark (basalt)	0–2	2.76	2.05	0.21	0.11
Do	12	1.98	2.01	.24	.11
Western yellow pine forest (basalt)	0–2	2.37	2.26	.20	.16
Do	12	2.05	2.23	.18	.12
Western yellow pine forest (Kaibab limestone)	0–2	2.39	1.93	.13	.11
Do	12	.87	.96	.12	.04
Douglas fir (acidic volcanic)	0–2	4.77	2.09	.12	.33
Do	12	4.43	1.79	.16	.20
Engelmann spruce (acidic volcanic)	0–2	3.81	3.16	.15	.26
Do	12	4.34	1.89	.13	.09
Timber line (acidic volcanic)	0–2	5.65	2.02	.30	.32
Do	12	4.16	2.01	.25	.18

[1] Analyses by U. S. Bureau of Chemistry and Soils.

TABLE 23.—*Acidity and alkalinity of soils at a depth of 6 inches in different vegetational zones of the San Francisco Mountain region*

Forest type and soil origin	Location	Altitude	pH[1]
		Feet	
Grassland (Kaibab limestone)	East of Canyon Padre	5,000	8.2
Piñon-juniper (Kaibab limestone)	Near Walnut Canyon, ridge	6,500	8.0
Do	Near Walnut Canyon, valley	6,500	8.0
Western yellow pine (basalt)	Sample plot S–3–A	7,300	7.0
Do	Fort Valley	7,300	7.0
Western yellow pine (cinders)	East of cliffs	7,000	7.0
Douglas fir (acidic volcanic)	San Francisco Mountains	8,700	7.0
Douglas fir-aspen (acidic volcanic)	do	8,700	6.8
Engelmann spruce (acidic volcanic)	do	10,500	6.5
Timber line (acidic volcanic)	do	11,500	6.5

[1] Determinations by the Wherry method (47). Values above pH 7 indicate alkalinity; those below, acidity.

PHYSICAL CHARACTERISTICS

Investigations in the western yellow pine zone have shown that within soil areas of similar origin growth is usually best in the more sandy or gravelly soils. (Fig. 31.) This relation is so general in the Southwest that texture appears to be more important than chemical composition, particularly in the growth of seedlings. (Fig. 32.) Also in clay soils reproduction is always better where there is a mixture of rocks. Similar observations made in the Douglas fir zone again point to permeability as the dominant factor. It is a matter of common observation that western yellow pine roots penetrate most deeply in the sandy or gravelly soils (fig. 33, A and B), probably because these soils are also most permeable to moisture and air. Penetration is also good among rocks, provided they do not offer excessive mechanical resistance.

Topography, geologic origin, and climate all have an important bearing upon physical composition of soils. Naturally the finest soils are found in the valleys, although there may be sandy or

FIGURE 31.—Western yellow pine on a rocky eminence in a park within the western yellow pine type. The surrounding grass-covered area has a clay loam or clay soil, usually unfavorable to pine reproduction unless mixed with a large proportion of stones. (Photo by J. O. Veatch)

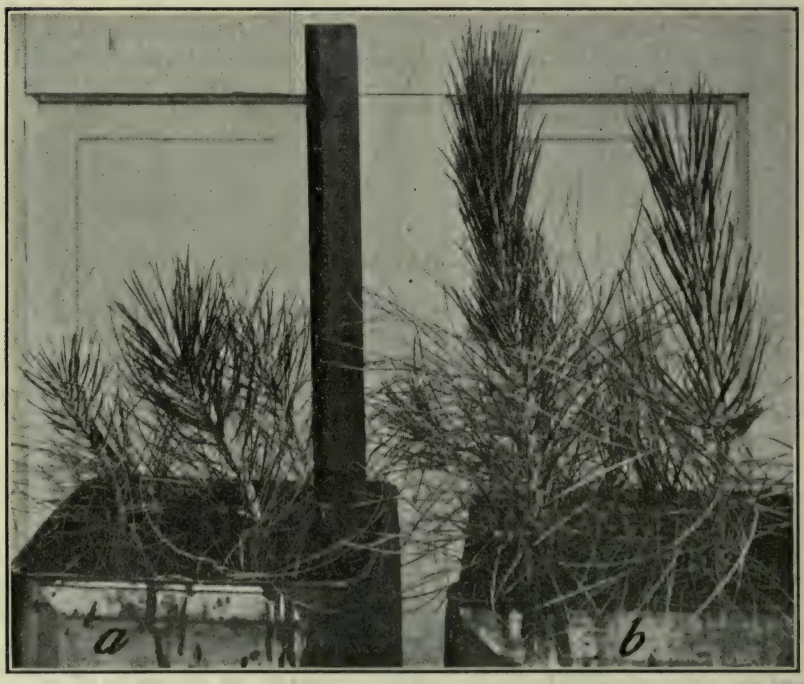

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FIGURE 32.—Western yellow pine seedlings of the same age in two kinds of soil: *a*, Clay subsoil from western yellow pine forest; *b*, surface soil mixed with 50 per cent sand

gravelly deposits in such situations. Slopes are more likely to be made up of coarse material, especially if bare enough to permit surface erosion. A good illustration of the effect of geological formation is seen in comparing soils derived from basalt on the Colorado Plateau with those from the so-called acidic rocks where they occur under similar conditions of climate and topography. The acidic rocks are more crystalline and when disintegrated yield a greater proportion of sand and less clay than does the basalt. The basaltic soils are usually very heavy, and but for the presence of

FIGURE 33.—Root systems of western yellow pine in different soils: A, On deep gravelly soil. Here there is no well-defined taproot but a large number of small ones which go straight down. The lateral system near the surface is also strong. The auger shown near the center of the picture is 40 inches long. B, Shallow root system typical on the more compact soils

organic matter, rocks, and gravel beyond the largest size considered in the mechanical analyses here presented, would be somewhat impermeable, especially after being thoroughly leached. Table 24 shows this relation fairly consistently. The limestone and sandstone vary considerably but usually yield a fairly permeable soil. The subsoil in the Kaibab limestone formations is commonly a heavy clay. Perhaps the most porous soil and one of the most productive under favorable conditions of climate and topography is the disintegrated granite. On steep slopes, however, unless a good vegetative cover is maintained, it tends to erode badly, with consequent loss of fertility.

TABLE 24.—*Physical characteristics of soils in the San Francisco Mountain region*

Laboratory sample No.	Forest type and site, with soil origin	Vegetation	Depth	Moisture equivalent [1]	Wilting coefficient [1]	Water-holding capacity	Mechanical analysis [2]						
							Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
	Western yellow pine:		*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
47	Valley (Kaibab limestone, few stones).	Forest logged, tall grass	0–2	20.61	11.20	51.05	4.0	2.3	0.5	11.4	36.6	36.5	8.6
48	do	do	12	9.30	5.05	40.45	2.2	3.1	.8	24.8	49.0	14.2	5.8
49	Rocky ridge (Kaibab limestone, stony).	do	0–2	19.52	10.61	53.60	3.0	2.5	1.0	16.0	42.8	26.4	8.0
7	Level mesa (basalt, stony)	Virgin forest, grass and other herbs, close grazing.	0–2	23.70	12.88	47.85	3.1	5.4	2.4	9.5	19.4	45.9	14.2
13	do	do	12	23.40	12.72	56.80	1.3	3.6	2.6	12.1	13.0	41.6	25.9
8	do	do	12	21.39	11.62	55.80	6.0	9.3	2.4	7.1	16.6	40.2	18.3
14	do	do	24	26.04	14.15	63.00	.6	3.9	2.5	12.4	16.0	39.0	25.5
9	do	do	24	25.02	13.60	59.45	4.8	7.0	3.0	10.2	16.4	37.4	21.4
11	do	do	30	23.99	13.03	62.30	8.8	16.5	7.5	23.0	8.1	20.0	15.9
10	do	do	36	38.90	21.14	78.00	2.1	11.8	4.2	14.8	4.8	38.8	23.1
12	do	do	0–2	27.85	15.13	57.60	2.4	5.6	2.9	12.4	13.3	47.7	15.6
16	Flat (basalt, few stones)	do	0–2	25.50	13.86	48.85	1.3	4.0	2.1	9.2	18.0	50.4	14.8
17	do	do	12	24.78	13.47	62.95	1.8	5.0	2.4	11.0	14.3	40.2	25.0
18	do	do	24	26.38	14.33	64.20	2.4	5.4	2.6	10.8	10.5	43.8	24.2
4	Park (basalt, no stones)	Treeless, grama grass, close grazing.	0–2	20.49	11.13	45.63	5.4	7.6	3.2	13.0	19.0	38.2	13.6
5	do	do	12	22.70	12.34	64.65	3.0	6.8	3.3	14.2	15.0	37.2	20.5
6	do	do	24	21.85	11.87	55.13	10.6	12.0	3.6	13.3	13.4	33.2	13.9
	Douglas fir:												
31	Northwest slope (acidic volcanic, rocky).	Virgin forest, conifers	0–2	33.73	18.33	90.80	6.0	10.0	2.6	11.4	11.0	44.1	14.6
32	do	do	12	23.52	12.78	69.00	8.6	10.4	2.4	10.2	12.5	40.3	15.6
33	Bench (acidic volcanic, rocky)	Aspen and young conifers	0–2	30.95	16.82	75.55	2.6	7.3	3.2	14.4	11.3	47.3	13.9
34	do	do	12	23.99	13.03	64.30	1.6	5.8	3.4	15.1	12.6	45.8	15.4
35	Park, south slope (acidic volcanic, few rocks).	Treeless, grassy	0–2	27.65	15.03	70.80	3.0	8.2	3.3	16.2	13.4	42.2	13.6
36	do	do	12	25.53	13.88	67.90	2.1	7.4	3.8	17.3	12.2	44.6	12.6
	Limber pine-bristlecone pine:												
43	Steep southwest slope (acidic volcanic, few rocks).	Scattered pine, grassy, close grazing.	0–2	22.85	12.43	58.00	6.6	11.6	4.0	14.4	12.2	40.7	10.3
44	do	do	12	21.62	11.75	56.05	5.0	9.8	4.1	13.8	11.4	42.7	13.2
45	do	do	12	22.60	12.28	60.10	7.1	12.3	4.2	12.1	9.4	43.5	15.2

37	Engelmann spruce: Northwest slope (acidic volcanic, rocky).	Dense forest	0–2	34.59	18.80	107.10	6.6	12.8	3.4	13.9	11.0	38.8	13.4
38	do	do	12	20.90	11.36	66.70	21.0	14.2	2.3	8.1	8.2	33.9	12.0
39	Ridge (acidic volcanic, rocky)	Small opening, grassy	0–2	30.60	16.63	75.80	6.2	9.1	3.4	12.1	11.2	42.8	15.0
40	do	do	12	27.30	14.84	69.15	6.8	8.4	3.1	10.5	10.0	42.4	18.7
	Timber line:												
46	Ridge (acidic volcanic)	Bushy trees, grassy	0–2	15.73	8.55	44.30	43.5	13.4	1.5	5.4	5.4	21.7	9.0
41	do	do	12	27.99	15.21	77.35	3.8	8.9	4.2	17.4	13.0	38.1	14.5
42	do	Bare	12	9.52	5.17	37.55	13.4	9.1	3.0	10.7	10.0	39.3	14.4

[1] Bureau of Plant Industry, centrifugal method. Percentages based on dry weight of soil.
[2] Bureau of Chemistry and Soils. Soil particle sizes as follows: Fine gravel, 2 to 1 mm.; coarse sand, 1 to 0.5 mm.; medium sand, 0.5 to 0.25 mm.; fine sand, 0.25 to 0.1 mm.; very fine sand, 0.1 to 0.05 mm.; silt, 0.05 to 0.005 mm.; and clay 0.005 mm. and smaller.

The capacity of soils for absorbing and holding water is termed "water-holding capacity," and the relative freeness with which they give up moisture to plants is indicated by the wilting coefficient. Soils which have the highest water-holding capacity also have the highest wilting coefficient or are able to withhold a higher percentage of water from the plant. These qualities are exhibited in the highest degree by the clay soils and in the lowest by sandy soils. Theoretically, the difference between water-holding capacity and wilting coefficient represents the net amount of water available to plant roots. But the soils having the largest capacity for available water are usually not the ones best able to sustain plant life in periods of drought.

The effects of drought are usually first apparent on clay soils, probably because of the low permeability to both water and roots. After a clay soil of good structure becomes saturated to a depth of 4 or 5 feet, the plants on it, if roots are able to penetrate to this depth, are in a position to resist drought. But if the moisture is not sufficient to saturate the lower strata or if the roots are not able to penetrate deeply the condition is different. A rainfall of 4 or 5 inches in July usually does not penetrate more than a foot in clay soil. In a sandy, gravelly, or stony soil, the same amount of moisture may penetrate 2 or 3 feet. In other words, the clay soil has a higher moisture content in the upper foot but may be dry below, and the more permeable soil has less moisture in the surface foot but stores a considerable quantity in the second and third feet. According to investigations elsewhere the water loss by evaporation from below the surface foot is very slight. Thus, if the clay soil is moist only in the surface foot all of its moisture is exposed to evaporation, whereas the more permeable soil has a supply in the second and third feet which is not affected by direct evaporation.

In the Southwest the soils of intermediate water-holding capacity and wilting coefficient usually provide the best moisture conditions. Those of low water-holding capacity and low wilting coefficient, that is, sandy or gravelly soils, may be more favorable to reproduction but less favorable to timber growth. Relatively high water-holding capacity and wilting coefficient are favorable if they are the result of humus rather than clay content, because although humus may withhold water to a considerable extent it increases permeability and fertility. It is seldom, however, that organic matter occurs in sufficient quantities below the upper foot of soil to be of appreciable importance in this region. In the Douglas fir and Engelmann spruce zones, the water-holding capacity and wilting coefficient are highest in the surface-soil samples, because of the presence of humus: but in the western yellow pine and lower zones the relation is usually reversed, because there humus is a minor factor and the clay content is greatest in the lower strata.

SOIL ZONES AS RELATED TO CLIMATE

As has been indicated in the preceding pages, the character of a soil is influenced in large degree by climate, through its influence upon the rate of disintegration of the parent rock, concentration of salts, leaching, and accumulation and decomposition of organic matter. The relation between climate and soils was studied in the

San Francisco Mountain region during the summer and fall of 1919 by J. O. Veatch,[17] assigned to this work by the Bureau of Soils. The results of Veatch's investigation have not been published, but the Bureau of Chemistry and Soils has kindly consented to the use of material from his report. The following discussion of soil zones consists of extracts from this report:

In the region outlined from the San Francisco Peaks down to the desert in any direction, embracing a range in altitude roughly of 8,000 to 10,000 feet, there is a great diversity in soil. As this can not be accounted for on a purely geologic or purely topographic basis, it is believed that the group characteristics of mature or old soils have been determined by climate. An attempt is here made to define the soils into broad groups or zones and to state the relation of each zone to certain elements of climate. The observation in mountainous regions that soils change with altitude and differences in precipitation is not new, but the attempt to establish limits for major groups of soils and to define those features which are determined by climate in contradistinction to those which are geologic is still somewhat in the nature of pioneer work in soil science.

In the San Francisco Mountain region, beginning at the lowest altitudes and in the region of least precipitation and highest temperature, the soils exhibit the lowest content of humus, this being practically absent and never sufficient to produce a pronounced brownish tint; the prevailing soil color is gray or else is inherited from the rock which constitutes the soil or from which the mineral base of the soil is derived. With increase in altitude, there is an increase in humus until the maximum thickness of humus and intensity of humus color are reached in an altitudinal belt ranging from 8,000 to 10,000 feet, thence there is again a decrease (ignoring in some instances a thick covering of forest mold consisting mainly of unhumidified organic matter) to the tops of the San Francisco Peaks. In both the highest and the lowest soil zones there is at best only a small supply of plant matter as a source of humus. In the desert, this is largely consumed by natural combustion or oxidation due to high temperatures and a very high percentage of sunshine; at the alpine heights the low temperature probably limits the activity of decomposing bacteria.

The changes in texture and structure with altitude and climate are analogous to those in humus. In both the desert and at alpine heights the soils in general may be described as psammogenous (characterized by a maximum content of coarse particles, sand, gravel, and stone, with a minimum of clay). Clay soils in both instances are practically absent except where purely geologic. Between the two extremes, pelogenous soils (those containing a high percentage of fine particles, clay and silt in size) are developed.[18] The maximum content of clay seems to be developed in a zone between 7,000 and 8,000 feet. Here temperature is sufficiently high and moisture sufficiently abundant for the decomposition of minerals into clay but without an excess of water which would cause leaching. Again the clay content in soils decreases with increase in elevation, so that at alpine heights the content of silt and clay is no greater than in the desert or at the lowest elevations.

The content of calcium carbonate and other alkaline salts is highest in the desert or belt of least precipitation and highest evaporation, with a gradual decrease in the percentage up to altitudes of 7,000 to 8,000 feet, where the amount of calcium carbonate is rarely sufficient to produce free effervescence with acid, and where the soils are nearly neutral in reaction. Although no laboratory investigations have been made, it would appear that there might be an increase in acidity, due to the formation of a spongelike or feltlike mold of semidecomposed plant matter, up to 11,000 to 11,500 feet, and a grayish or leached horizon directly beneath the mold.

Intensity of iron oxide coloring as a phenomenon of soil-forming processes seems to be greatest in a zone from about 6,500 to 8,000 feet. Here pro-

[17] VEATCH, J. O. SOILS AND THEIR RELATION TO CLIMATIC AND VEGETATIONAL BELTS, SAN FRANCISCO MOUNTAIN REGION, ARIZONA. Unpublished manuscript.

[18] The terms "psammogenous" and "pelogenous" were coined by Thurman, the Swiss investigator, whose writings are quoted in part by Schimper (*39, p. 101*). These terms, with slight modification of their original meaning, may be made to serve a useful purpose in regional descriptions of soils.

nounced reds and yellows in the subsurface horizon of the soil profile are observed. At higher elevations pale reds, and pale yellows, lavender, light grayish-chocolate, and lemon yellow are prevailing shades; below this middle zone down to the true desert, oxidation colors become gradually less intense until grayish soil color predominates. Both in the highest and lowest zones pronounced reds and other shades are present which are inherited from the rocks which furnish the mineral base of the soil.

Comparisons of the thickness of the soil cover or residuum of weathering may not be without value. The soil cover in the desert is less, other things being equal as nearly as possible, than at the intermediate elevations. The rather popular conception of arid soils as being of great thickness has been derived from observations on irrigated desert soils, which from the nature of things are generally situated in valleys and on terraces where the greatest thickness of wash or alluvium has accumulated, and in some instances the soil is practically synonymous with a geologic formation. Probably the greatest thickness of the soil proper is at 7,000 to 9,000 feet altitude, thence there is again a much smaller thickness near and above timber line.

Within an altitudinal range amounting to 8,000 to 10,000 feet six separate soil groups are differentiated. These are designated by geographic names for the purpose of convenience of reference and description. There is a blending of the features of one soil zone with the succeeding zone above and below, in conformity with the gradual change in climate and vegetation from one climatic and vegetational belt to another, so that within certain limits a line of division drawn on a map must necessarily be somewhat arbitrary. In general, however, fairly definite altitudinal limits can be given to the separate soil groups. However, soil types having the same essential characteristics may frequently be found considerably above or below the altitudes at which normally they would be expected. Were the slope an ideal one, that is with perfectly smooth surface and uniform gradient, these exceptions would not appear. They are due mainly to differences in topography and direction of slope as affecting the amount of moisture and temperature in the soil, as for example on steep north-facing slopes of canyons, say at an elevation of 6,500 feet, where a soil high in humus and low in lime, supporting a growth of western yellow pine, Douglas fir, and aspen may be found; although normally, high lime soils, supporting a growth of western yellow pine, piñon, juniper and semidesert shrubs are found at this elevation. Evaporation is a factor which has to be taken into consideration even where precipitation is the same. Peculiar local geologic conditions affecting the structure of the soil also account for these adventitious types. As for example on the slopes of cinder cones at 7,000 to 8,000 feet, soils frequently exhibit some of the normal characteristics of soils at 6,000 to 7,000 feet. The nature of the soil or rock is such that only very small amounts of water are held near the surface, and on account of the very open porous condition and lack of humus covering, there is a high percentage of loss through evaporation.

DESCRIPTION OF THE SOIL ZONES

In the region outlined, six separate soil zones are differentiated. These are designated by geographic names for convenience of reference and description. The plan of description here presented is original, and the names for the zones have not heretofore been used in soil literature.

NAVAJOAN ZONE

The Navajoan is largely desert; its altitude is generally below 5,500 feet. The climate is hot and semiarid, and the annual precipitation is less than 12 inches.

The soil profiles in general have the following characteristics: Grayish surface soil (the tints or colors of which are inherited from the rocks without appreciable change); very low or practically no humus content; high percentage of calcium carbonate and other easily soluble salts throughout; "caliche" (whitish layer of cementation, mainly by calcium carbonate,) at variable depths; and nearly uniform texture and structure above the caliche layer or above the unaltered geologic substratum, (the separate horizons being at most

only obscurely marked). In this zone, the action of the climate is such that distintegration generally exceeds decomposition, so that the soil may be classed as psammogenous.

Moisture because of low precipitation, ordinarily descends to only a slight depth and is quickly transpired or lost directly through evaporation. Shallow soils are extremely dry; in deep soils the reservoir of moisture is in substrata lying at great depths.

It is not improbable that differences in soil characteristics between the most arid regions (such as are commonly termed desert) of the Colorado Plateau on the one hand and those of that physiographic region lying south of the plateau rim, embracing southern Arizona and most of southern New Mexico, are appreciable. The writer is inclined to group tentatively the most arid soils of the two regions separately, largely on the assumption that the differences in mean temperature and evaporation have affected soil differences. Limited observations in the two regions indicate that more intensive oxidation colors, with development of reddish ferric oxides, and higher percentages of silt and clay (geologic and topographic conditions being as nearly as possible the same) prevail in the southern region. The zone of most arid soils in the southern region is given the name Jornadan. Possibly the soils at the lower altitudes in the Verde River Valley just below the rim of the San Francisco Plateau should be included in the Jornadan zone.

UTAHAN ZONE

The Utahan zone corresponds in altitude to the piñon-juniper type; approximate altitudinal limits 5,500 to 6,500 feet; moderate temperatures; annual precipitation 12 to 15 inches.

The generalized profile of the Utahan zone shows the following layers: (1) A loose and finely granular grayish to pale-brownish surface layer; (2) a layer showing very slight clay concentration and slight cementation from soil salts; (3) a highly calcareous layer, drier and more friable than the layer above; and (4) the geologic substratum. The humus layer is very thin, and the content of humus is low, but in many places sufficient to produce light-brownish tints at the surface. The soils are moderately high in lime and mineral plant food from the surface downward. They are psammogenous for the most part.

COLORADAN ZONE

Corresponds to the western yellow pine type; altitudinal limits of the lower Coloradan approximately 6,500 to 7,000 feet and of the upper Coloradan 7,000 to 8,500 feet; cool climate; annual precipitation, much of which is snow, 18 to 25 inches.

The generalized profile of the Coloradan zone shows soil layers from the surface as follows: (1) Neutral or very slightly calcareous pale-brownish to chestnut-brown surface soils in which the humus color may frequently extend to a depth of several inches; (2) heavier-textured and less pervious subsurface layer, in which yellowish, brownish, and reddish oxidation colors reach maximum intensity; (3) a more friable layer (containing less clay than layer No. 2) in which there is a very low to moderately high content of calcium carbonate; and (4) geologic substratum.

This zone can be conveniently divided into upper and lower members. In the lower Coloradan, there is sufficient humification to produce only light brownish tints; the intermediate subsurface layer shows a slight cementation from soil salts; and the lower part of the soil profile is frequently highly calcareous. In the upper Coloradan zone there is sufficient true humus to produce brownish tints; but the climate is not sufficiently moist to permit an appreciable accumulation of plant mold or duff in forests. The intermediate layer is heavier in texture than the surface soil and frequently is notably stiff and compact but shows no great degree of cementation due to concentration of soluble salts. Soil colors due to oxidation of iron minerals reach maximum intensity in this zone. The soils are neutral or but slightly alkaline and apparently do not exhibit high percentages of lime in the form

of carbonate in any part of the soil profile, though neither do they exhibit evidence of excessive leaching. They are high in fertility.

In the Coloradan zone, silt loam, clay loam, and clay are more common textures than in the two zones previously described; that is, the soils on the whole are pelogenous rather than psammogenous.

DATIL ZONE

The Datil zone corresponds to the Douglas fir type; altitudinal limits approximately 8,500 to 10,000 feet; cool humid climate with smaller range of temperature than in the Coloradan zone; annual precipitation, the greater part of which is snow, 25 to 30 inches.

The generalized profile of the Datil zone shows the following layers: (1) Thin covering of mold in forests, mild humus rather than acid; (2) comparatively thick brown or dark-brown surface soil, containing sufficient humus and organic matter to produce loamy texture; (3) layer heavier in texture than the surface soil but showing no cementation or notably stiff or compact condition; and (4) geologic substratum.

In the Datil zone, the process of humification has probably proceeded farther than in any other zone. Red soil color is less pronounced and less common than in the Coloradan zone. The content of lime carbonate is low, except where this is purely a geological phenomenon. In this zone, weathering agencies would be expected to effect a relatively greater amount of decomposition than in other zones, but locally the percentage of finer particles is perhaps no greater than in the Coloradan zone, because in this region most of the soil is derived from coarse alluvial wash and the bowlders of rock slides or avalanches.

AGASSIZ ZONE

The Agassiz zone corresponds to the Engelmann spruce type; altitudinal limits approximately 10,000 to 11,500 feet; colder than the Datil zone and precipitation slightly higher.

The layers in the generalized profile in the Agassiz zone are as follows: (1) Comparatively thick layer of mold, the plant matter showing very little humification and acidity; (2) an underlying humus layer, of low humus and very low lime content, and acid in reaction; (3) thin or very thin layer showing no evidence of considerable concentration or accumulation of clay, pale or obscure in color, and low in lime content; and (4) geologic substratum.

The forest soil is characterized by a thick feltlike covering of mold or accumulation of unhumidified plant matter, which is sharply separated from the underlying mineral soil. In many places the mineral soil for a half inch to 2 or 3 inches has a grayish, ashy appearance. The oxidation colors are pale or dull yellows and light browns. Probably less clay is formed under the weathering agencies which prevail than in the Datil and Coloradan zones. In the unforested areas or grass-covered glades, a loose, fluffy grass mold is present. The humus color here is darker or more pronounced than in the forest, and it may be reasonably inferred that more available nitrogen is present.

FRANCISCAN ZONE

The Franciscan zone coincides with the alpine vegetation zone above the upper limits of tree growth, which in the San Francisco Mountains is about 11,500 feet. The climate is alpine or boreal, and the region may be described as a cold or arctic desert.

The soils of the Franciscan zone represent an extremely thin cover over the hard rock. They can be described as psammogenous or containing extremely small percentages of silt and clay. Little or no change in texture takes place with depth, and the soils are very open, pervious, and nonretentive. Humus is present in very small quantities or is lacking, and the content of lime is very low. The color is likely to be inherited from the rock or to show only pale-yellow oxidation tints. In the region under consideration prac-

tically the only loose soil is in pockets or crevices in rocks or in protected situations under rock ledges. Otherwise the soil consists of the hard rock which may be barren, lichen-covered, or covered by a mossy or peaty accumulation.

RÉSUMÉ OF FINDINGS ON CLIMATE AND SOIL

The significant facts about the climate and soil which seem to have a bearing upon plant distribution in the Southwest may be summarized as follows:

Temperature falls generally with rising elevation, but this is not so evident in the mean or in the minimum as in the maximum. The best insight into temperature conditions is obtained from a detailed analysis of thermograph records, which show not only lower maxima but a much shorter duration of high temperatures in the high than in the low altitudes. Temperature summations and particularly the physiological indices of temperature efficiency bring out these relations in a striking manner.

Soil temperature follows the course of air temperature only in a general way; current changes in the two may be directly opposite. This relation is explained by the fact that the soil derives more of its heat directly from solar radiation than from the air. Surface soil maxima are often much higher than the air maxima. At depths of a foot or more both the maximum and the minimum are greatly tempered so that the diurnal fluctuations are reduced to 1° F. or less. Anything which affects the incidence of solar radiation upon the ground affects the soil temperature correspondingly. Thus, soil temperatures are distinctly lower in the shade of trees than in the open and on north than on south slopes.

Soil moisture is determined mainly by precipitation but is modified by the physical characteristics of the soil and by temperature, humidity, and movement of the air. Precipitation increases rapidly and uniformly with altitude up to the Douglas fir zone, beyond which the increase becomes less perceptible. Seasonal distribution is practically the same from desert to timber line in the same locality. Corresponding forest types receive slightly less precipitation in New Mexico than in Arizona, and there is also a noticeable difference in seasonal distribution. On an average, a given forest zone in New Mexico receives less precipitation in winter and more in May and June than the same zone in Arizona.

Physical composition of soils appears to affect plant growth much more than chemical composition. Deep, moderately sandy or gravelly soils are most favorable for all tree species. Clay soils are generally adverse to natural reproduction, but unless extremely heavy they favor good development of trees which have passed the seedling stage. Soils derived from granite, sandstone, and the acidic volcanic rocks are usually lighter and more permeable than those derived from limestone and basalt, although both the limestone and basaltic soils become fairly permeable when mixed with sand, gravel, or stones. Climate is probably fully as important as geologic origin in determining the depth and physical characteristics of a soil. This also applies to chemical characteristics in so far as they are modified by the influence of moisture upon soluble salts and by the influence

of both heat and moisture upon the presence and decomposition of organic matter.

CHARACTERISTICS OF THE SPECIES

Much information regarding the habits of forest trees in the Southwest has been accumulated by many persons through years of observation. Although much of this is known to foresters, it seems desirable to bring together the most salient facts before any attempt is made to correlate physical conditions with distribution of species. In addition to this rather general information, the results of several recent experiments and systematic observations will be presented. Throughout this discussion the aim will be to stand the various species side by side, so to speak, and compare them with respect to all features on which information is available.

RELATIVE HEAT REQUIREMENTS

Heat requirement is too complex a question to be answered by observational methods. If one may judge by the temperatures prevailing where the principal conifers of the Southwest are found naturally, the order of the species with regard to heat requirement, beginning with the highest, is about as follows: One-seed juniper, Utah juniper, piñon, Arizona cypress, alligator juniper, western yellow pine, limber pine, white fir, Douglas fir, blue spruce, bristlecone pine, corkbark fir, and Engelmann spruce. In the following pages, observations and experimental data on the relative heat requirements of several species will be cited. Absolute requirements or, rather, the range of requirements presents another problem, which will be approached later.

FROST RESISTANCE

A phase of heat requirement which has received much attention in European forestry is resistance to frost. In a region where unseasonable frosts are so prevalent as in the mountains of the Southwest, this would seem at first thought to be a matter of very great importance. As far as native species are concerned, however, the frost problem seems to be fairly well met either by resistant qualities or by adjustment of distribution. None of our native species have been observed to suffer unduly from frost in their natural habitats; it is when they are taken away from home that they are likely to be injured. A large part of the frost damage reported in Europe is no doubt to be accounted for by the introduction of exotic species or by the artificial transplanting of indigenous species on naturally treeless sites. Douglas fir is an American species which is peculiarly subject to frost injury in Europe. In this country it appears to avoid frosty sites; the seedlings which start on such sites are either killed outright or are so severely injured that they can not compete with their neighbors. This species has been found to suffer severely from frost when planted in the western yellow pine zone at the Fort Valley station, where, although day temperatures are much higher than in the Douglas fir zone, night temperatures are likely to be lower. Blue spruce, under similar conditions, suffers to only a slight extent. Norway spruce and Scotch pine (Riga variety), both ex-

otics, have been grown on the experiment station grounds since 1910 and have at no time shown appreciable effects of frost. Western yellow pine first-year seedlings have been known to be killed by fall frost on a few occasions. Observations in 1908 led the writer to surmise that this is a common cause of damage, but experience since then indicates that frost damage to western yellow pine in its native habitat is mainly to seedlings which germinate late in the summer. First-year nursery-grown seedlings of western yellow pine from seed collected on the Sierra National Forest of California were on one occasion completely killed by a November freeze, while plants from seed collected in Arizona, New Mexico, Colorado, and the Black Hills of North Dakota were uninjured.

TEMPERATURE RESPONSE

As has already been pointed out, observations in the field under many conditions and where several species are found side by side indicate that western yellow pine responds more slowly to the stimulus of rising spring temperatures than do Douglas fir, blue spruce, and white fir. Bristlecone pine likewise responds more slowly than corkbark fir and Engelmann spruce when the three appear on the same site. All the pines are able to go far above their usual upper limits by taking advantage of steep south slopes and ridges where the amount of heat available is probably higher than air temperatures indicate. This is especially true of bristlecone pine, which in the higher altitudes of this region occurs almost exclusively on south slopes and ridges, reaching up to 11,500 feet in elevation.

In the late fall of 1919, potted plants of western yellow pine, Douglas fir, bristlecone pine, and blue spruce taken from out of doors were placed in the greenhouse at the experiment station. No heat was applied, and the plants remained dormant until the latter part of February. From February 1 until March 20, the mean temperature fluctuated greatly, but the maximum rose above 75° F. on most days. The dates on which the buds began to open are as follows: Blue spruce, February 28; Douglas fir, March 12, and western yellow pine and bristlecone pine, March 22. On the experiment station grounds it has been observed year after year that the blue spruce and Douglas fir seedlings begin growth about a week earlier than western yellow pine.

The beginning of root growth in the spring has been observed in the experiment station nursery. Soil temperature was recorded with thermometers at a depth of 6 inches; in 1920 the cylinder of a soil thermograph was placed among the roots. Western yellow pine roots began to grow, as indicated by the appearance of white root tips, when the maximum (afternoon) soil temperature 6 inches below the surface rose to between 52° and 54° F. four days in succession. Bristlecone pine and Douglas fir began growing when corresponding temperatures reached 50° to 52° F. In May, 1914, blue spruce roots were growing vigorously when afternoon temperature ran up to 49° or 50° F., and western yellow pine roots showed no signs of activity.

In the spring of 1920 an experiment was carried out in the experiment station greenhouse with the object of comparing species as

to rate of germination in low and relatively high temperatures. In the absence of facilities for maintaining a contemporaneous series of gradations in temperature, three lots of seeds were sown at different times, the first on February 19, the second on April 1, and the third on May 1. No artificial heat was used in the greenhouse, it being thought that the natural rise in temperature with the advancing season and increasing length of days would be sufficient to influence germination to a noticeable degree. During clear weather, even in winter, high temperatures are attainable under glass and a large proportion of this heat is retained at night; but when the skies are overcast, as they may be for several days at a time during winter storms, little heat is stored during the day, and night temperatures drop to a low point. An effort was made, by ventilation, to keep the maximum air temperatures below 90° F. and, by closing the greenhouse in the afternoon, to keep the minimum well above freezing. High maxima were avoided, but freezing or near-freezing temperatures were of rather frequent occurrence in March and April. The daily range was comparable to that of the western yellow pine type but was considerably higher than that which usually prevails in the Douglas fir and Engelmann spruce forests. Soil temperature was measured with an ordinary thermometer, the bulb of which was placed about one-quarter inch below the surface of the soil.

Western yellow pine, bristlecone pine, Douglas fir, and Engelmann spruce were represented in the test. All the seeds except Douglas fir, which came from the Santa Fe National Forest in 1916, were collected in the San Francisco Mountains in 1918 or 1919. Two hundred seeds of each species were sown in tills 1 foot square and 4 inches deep, filled with sandy loam. With the exception of the Engelmann spruce seeds, which on account of their small size were covered only one-eighth inch, the seeds were pressed into the soil and covered to a depth of one-quarter of an inch with clean sand sifted over the surface. Water was applied in the evening in quantities judged sufficient to keep the surface moist through the following day.

According to the temperature and germination curves in Figure 34, the four species differ markedly in their response to heat. Bristlecone pine germinated well throughout the range of conditions existing here. Douglas fir and Engelmann spruce did better in the cold period of March and April than in the warmer period following the May sowing. Whether the low germination of these species in the last test was due entirely to high temperature is doubtful. On hot days the surface soil becomes somewhat dry, and this, rather than heat, may be the adverse factor. Engelmann spruce in particular would feel the effects of surface drought because of the slight depth to which the seeds were covered. Douglas fir also would be affected more than the pines, because the seeds are light and tend to work to the surface of the soil. Western yellow pine shows a clear preference for high temperature. In the March sowing this species started off fairly well during the first 20 days, which were relatively warm, but fell off sharply in the succeeding cold period and rose again with rising temperatures in May. The April curve for this species rises gradually until about May 25 and then shoots up abruptly when the mean air temperature reaches the 60° mark.

The May curve begins to decline at this point, evidently because most of the seeds had already germinated.

RELATIVE LIGHT REQUIREMENTS

There is a divergence of views as to the part played by light in the growth of trees. Early silviculturists were inclined to ascribe to

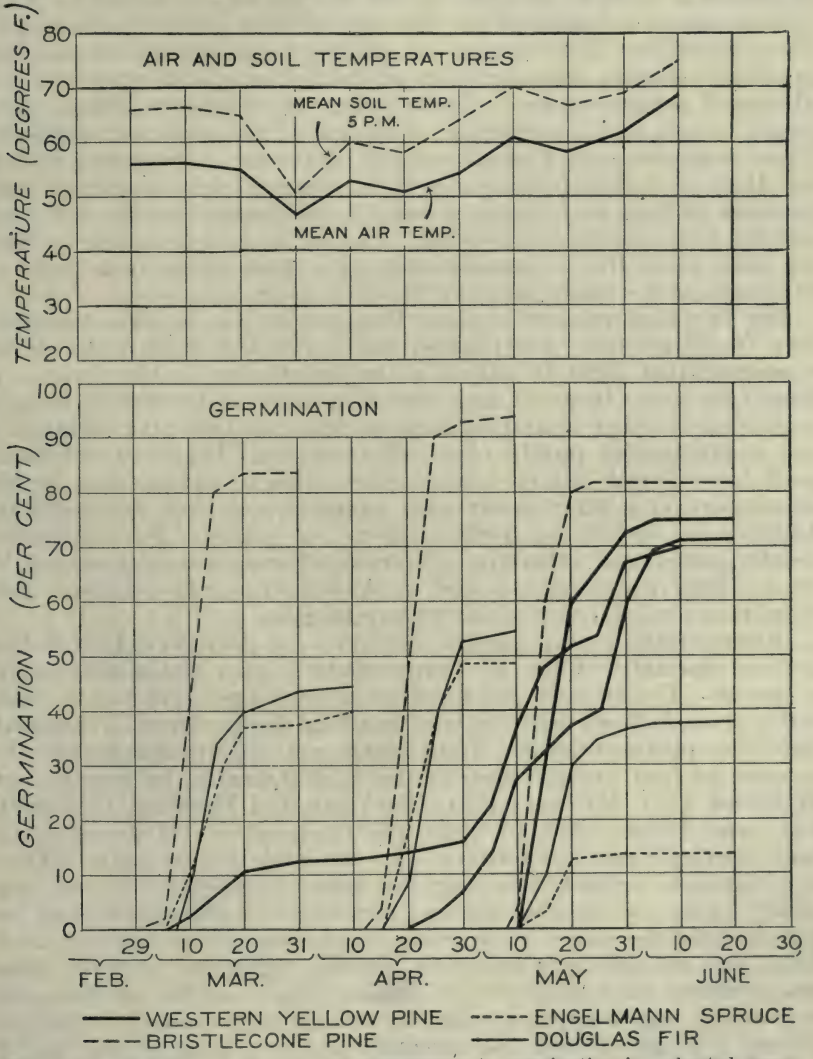

FIGURE 34.—Relation of air and soil temperature to germination in unheated greenhouse. Seed of four species sown February 19, April 1, and May 1, 1920

this factor every phenomenon which could be even remotely connected with it. Recent years have witnessed a swing toward the opposite extreme, some investigators now contending that light plays a relatively unimportant rôle. These more or less conflicting conclusions may be attributed in part to the absence of a uniform

conception of what constitutes light and in part to the intimate and often confusing relation between light and other physical factors.

Sunlight is made up of rays or vibrations varying in wave length and in their capacity to act on matter. The rays of short wave length are characterized mainly by chemical activity and those of long wave length by thermal activity, although neither chemical nor heating effect is confined to any one set of wave lengths. Luminous energy is exhibited only by rays of intermediate wave length. This distinction, however, is an arbitrary one, as it is based not upon any peculiar characteristics of the light rays but upon the sensibility of the human eye. Technically, only those rays whose wave length is such as to produce the sensation of vision are termed light. These comprise only a small portion of the solar spectrum, including that in which photosynthesis is centered but omitting large portions of heat and chemical energy represented by the infra-red and the ultra-violet, respectively. Obviously it is desirable in dealing with plant life to broaden our conception of the term light so as to include the entire range of the solar spectrum.

The fact that relatively weak illumination has in some instances been found adequate for photosynthesis has led some investigators to assume that light is seldom a limiting factor in the forest. It should be borne in mind, however, that light in the broad sense is concerned in other activities, such as transpiration and respiration and a number of purely chemical reactions. Light of relatively short wave length, which is most susceptible to interception by the atmosphere and other obstructing agencies, exercises an important influence in developing proper form in plants. The extremely slender stems and otherwise abnormal characteristics assumed by some plants in greenhouses and in shaded situations outside is said to be due to a deficiency of short wave lengths.

Direct sunlight may also be needed as a source of heat. This applies especially if the air temperature is near the minimum for a species. Under such circumstances, seedlings under cover may suffer from lack of heat, notwithstanding the presence of adequate light for photosynthesis. That plants may derive an appreciable amount of heat energy from sunlight is indicated by experiments by Seeley (*40*), Matthaei (*28*), Blackman and Matthaei (*5*), Smith (*42*), and Ehlers (*16*), in which the temperatures of leaves of the same species were compared in the sun and in the shade. These investigations agreed in finding the leaves exposed to the sun generally hotter by several degrees than those in the shade, and not infrequently the excess in the leaves in the sun was as high as 15° C. In a few instances the leaves in the sun registered slightly lower temperatures than those in the shade. This may be attributed to excessively rapid transpiration in the leaves exposed to the sun. Ehlers (*16*) points out that because of the cooling of the leaf as a whole by rapid transpiration the temperatures recorded for leaves in the sun are probably considerably lower than those within the chloroplast. Matthaei (*28*) found evidence of photosynthesis in *Prunus laurocerasus rotundifolia* in air temperatures as low as −6° C. when exposed to direct sunlight and suggests that in conifers under strong insolation, photosynthesis may take place at still lower temperatures.

Abnormal development of seedlings in the shade of older trees is not always due to deficient light or heat. If both these factors are above the minimum for the species, it is well to look for other causes, either independent or contributory. Fricke (*17*) found that Scotch pine (*Pinus sylvestris*) seedlings of poor development under an old stand responded vigorously when freed from root competition by trenching. Toumey (*43*) obtained similar results with northern white pine (*P. strobus*) in New England. In 1923 the writer undertook to ascertain to what extent the same relations hold for western yellow pine in Arizona. Two plots of unthrifty seedlings shaded about two-thirds of the day by groups of mature trees were trenched to a depth of 18 inches. Although the taproots of young pines penetrate deeper, a strong system of laterals, which are confined largely to the upper foot of soil, constitute the main feeders. In order to prevent drying from the sides, the trenches were refilled, but they were subsequently opened at intervals of from one to two years in order to cut any roots which had entered from the outside. The seedlings were from 4 to perhaps 9 years old and from 2 to 12 inches tall when the records were begun. At the end of five years only 10 out of the original 26 plants remained. The survivors had grown to heights ranging from 7 to 26 inches. During 1928 the height growth was from 1.4 to 3 inches, as compared with 3 to 5 inches for seedlings of the same age in more open situations near by. These results indicate that although the seedlings have probably been benefited by the removal of root competition, insolation, be it light or heat, is surely an important factor in the growth of western yellow pine. This conclusion is in harmony with the common observation in the Southwest that western yellow pine seedlings grow closer to old trees on the south than on the north side. On the other hand, the fact that growth is usually below normal even on the south side indicates that root competition is also a factor.[19]

Open stands do not always indicate intolerant species, nor does the occurrence of young seedlings under cover prove that they are tolerant of shade. The woodland species of this region are widely spaced because the rainfall is not sufficient to sustain a dense stand or because fires have killed the young growth. The same is true in the western yellow pine type. Seedlings of *Juniperus monosperma*, *J. utahensis*, and *Pinus edulis* grow under and immediately around old trees, forming a characteristic clump or circle. They are able to live in this partial shade, but they require abundant sunlight for good growth. Although low evaporation, soil cover, and seed supply under old trees favor germination, seedlings also start in open situations. Utah juniper, particularly, is noted for its ability to invade wide open spaces. Western yellow pine germinates best in the shade of old trees, because of the favorable degree of moisture at the surface of the soil; but the seedlings which start in such situations seldom live more than four or five years. For normal development, they usually require direct sunlight during one-half to three-fourths of the day.

[19] Since the preparation of this bulletin a number of publications on the light requirements of forest trees have appeared. These and some of the older works have been reviewed by the writer (*36*).

In the Douglas fir and Engelmann spruce types are better examples of shade tolerance. Here are extensive dense stands in whose shade seedlings of Engelmann spruce, white fir, and corkbark fir persist for many years. This is a valuable asset, for wherever a break in the cover occurs new growth is already on the ground and has a decided advantage over species which must start from seed. Douglas fir is less tolerant of shade than its common associate, white fir, and for this reason is unable to hold its own against white fir and other tolerant species in old stands. After a fire, however, Douglas fir has the advantage because it withstands drought better and grows faster than its rivals. In the transition between the western yellow pine and the Douglas fir types, western yellow pine finds itself at the same disadvantage as Douglas fir in the higher altitudes. Here Douglas fir and white fir, both of which are more tolerant than western yellow pine, are able to reproduce and persist under the old western yellow pines and to hold the ground when the pines die.

LIGHT MEASUREMENTS

In 1908 and 1909 the writer attempted to ascertain the minimum light intensities under which the various conifers are found in apparently normal condition. The photographic method first applied in ecological work by Wiesner (*48*, *49*) and improved by Clements (*10*, *11*) was used. In brief, this method employs a strip of sensitized paper which may be exposed a section at a time. The amount of discoloration is assumed to be proportional to the product of time by intensity. By timing the exposure and comparing the discoloration with standards exposed to full midday sunlight the relative value of any reading is obtained. This method has been criticized because it measures only the rays of short wave length. It would obviously be better to measure separately the intensity of different parts of the spectrum; but this calls for laboratory equipment which can not well be employed in the field. On the whole, the photographic method is probably as good as any available for field use. In Table 25 are presented the values obtained near Flagstaff, Ariz. The condition of the seedlings corresponding to the various light intensities is indicated by the classifications suppressed, fairly vigorous, and thrifty.

TABLE 25.—*Light intensities as related to vigor of seedlings*

Species	Suppressed trees	Fairly vigorous trees	Thrifty trees
Utah (one-seed) juniper		0.328–0.379	0.500–1.000
Western yellow pine	0.028–0.206	.309– .385	.414–1.000
Douglas fir	.016– .049	.097	.133– .192
Corkbark fir	.020		.028– .068
Engelmann spruce			.033– .062

This subject has more recently been studied by Burns (*7*) under laboratory conditions. Potted plants were exposed in bell jars to pure white light emanating from two 750-watt nitrogen-filled electric bulbs. The light intensity was measured by means of a vacuum

thermocouple. The activity of the plants was measured in terms of carbon dioxide absorbed from the air in the bell jar. When the percentage of carbon dioxide remained unchanged after an exposure of three hours, indicating that the amount used in photosynthesis was balanced by that given off in respiration, the light intensity was considered at a minimum for the plant in question. Of the 14 species tested by Burns, three, namely western yellow pine, Douglas fir, and Engelmann spruce, occur in the Southwest. The minimum light intensities under which these species were found to function normally are as follows: Western yellow pine, 30.6; Douglas fir, 13.6; and Engelmann spruce, 10.6. It will be seen that this order is the same as that given in Table 25.

Bates and Roeser (*4*) grew conifer seedlings from two months after germination to the age of 11 months in artificial light furnished by a 200-watt tungsten-filament, blue-glass lamp. The theoretical minimum light in which growth could be made, expressed in percentage of full sunlight, is given for six Rocky Mountain species as follows: Engelmann spruce, 1.1; Douglas fir, 1.5; western yellow pine, 1.8; lodgepole pine, 2.4; limber pine, 2.7; and piñon, 6.3.

RELATIVE MOISTURE REQUIREMENTS

ROOT SYSTEMS

The root habits of several species have been observed in the forest and in nurseries. Western yellow pine, Douglas fir, corkbark fir, blue spruce, and Engelmann spruce rank in depth of roots about in the order named. Western yellow pine has a deep taproot with long laterals, suggesting an adaptation to the necessity of obtaining moisture from a large volume of relatively dry soil. The spruces and firs, both in the forest and in the nurseries, develop relatively shallow but very compact root systems, evidently adapted to intensive utilization of the moisture in a small mass of soil. Douglas fir exhibits characteristics intermediate between the western yellow pine and the spruces and true firs. Piñon and alligator juniper show extreme development of the open though not always deep type of root, and this is equally characteristic of the limber pine and bristlecone pine in the few specimens examined. Arizona cypress develops a deep but fairly compact root system. Root pruning and transplanting encourage profuse branching in the roots of the spruces and Douglas fir, and, in less degree, in western yellow pine and Arizona cypress. Piñon, alligator juniper, and bristlecone pine respond still less to this treatment. Whether dry soil would induce the spruces and firs to develop a more open and extensive root system is not known. Observations made on full-grown trees indicate that the root habits exhibited in the seedling stage are to a large extent retained in after life. Engelmann spruce in typical stands has a compact, shallow, circumscribed root system. In open stands the laterals are more extensive, but in dense and open stands alike they seldom reach below a foot in depth. Western yellow pine roots reach depths of 6 or more feet in porous soils; on stiff clay soils they seldom go below 3 feet. In open stands laterals reach out 100 feet, but in dense even-aged stands they probably go but little beyond the spread of the crown.

TRANSPIRATION AND WILTING COEFFICIENT

Transpiration provides a measure of the rate of water consumption; wilting coefficient, or the moisture content of the soil when a plant wilts, indicates the capacity of the plant to remove water from the soil particles or the ability of the soil to withhold it. During 1919 and 1920, western yellow pine, Douglas fir, bristlecone pine, and blue spruce were compared with respect to both those functions.

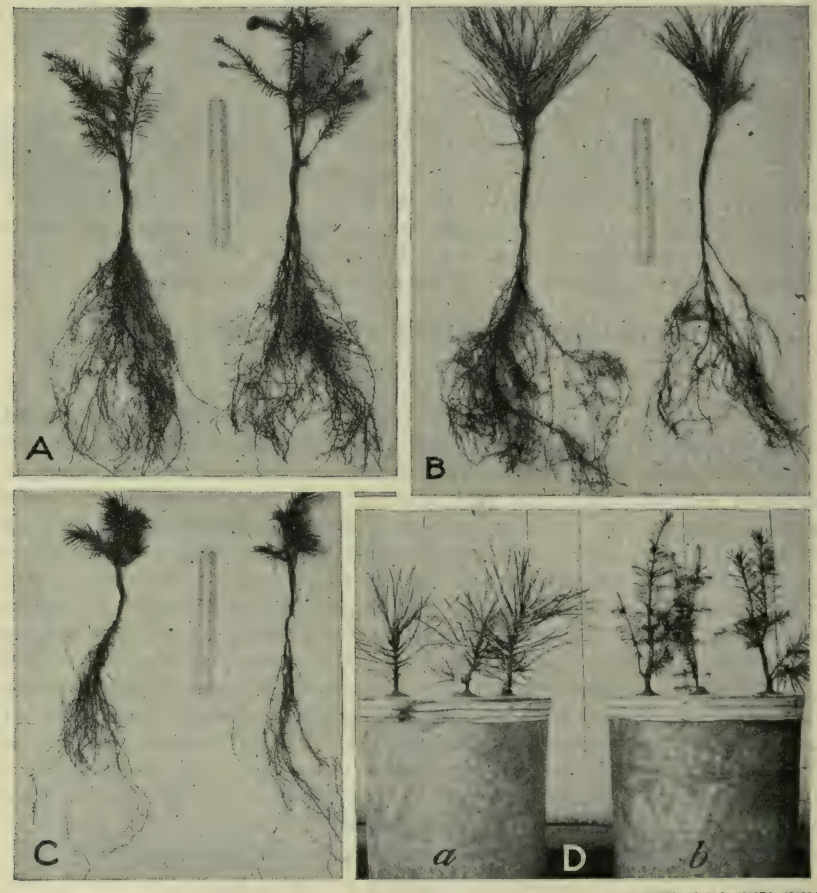

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FIGURE 35.—A, Douglas fir (4 years old) after two years in pots; B, western yellow pine (4 years old) after two years in pots; C, bristlecone pine (6 years old) after two years in pots; D, western yellow pine (*a*) and Douglas fir (*b*) in sealed pots for transpiration tests

Blue spruce was included under the misapprehension that it was Engelmann spruce, an error which was not discovered until the experiment was finished. Nursery-grown seedlings from 2 to 5 years old were planted in galvanized-iron pots (fig. 35, D) 10 inches deep and 9 inches in diameter. Three plants were placed in each pot. Metal covers were used, and all openings through which rain might enter were sealed with surgeon's tape or art clay. After each weighing, water was added until the weight of each pot was restored to

a value corresponding to a moisture content about 11 per cent above wilting coefficient. It is realized that this added water was not evenly distributed through the soil mass. During the growing season the plants were out of doors at the control station, and during the remainder of the year they were kept in an unheated greenhouse. In view of the fact that this experiment has previously been described (*35*), only the most essential facts will be related here.

For the purpose of this experiment it seemed preferable to refer water losses to increment in dry weight rather than to area of leaf surface. Table 26 indicates that the highest ratio of transpiration to accretion is in bristlecone pine, followed in order by western yellow pine, Douglas fir, and blue spruce. Except for the relative positions of western yellow pine and bristlecone pine, these results agree in a general way with those obtained by Bates (*1*) in Colorado. Because of the small number of plants used, the divergence between pots of the small species, and the small difference between average values for the several species, however, too much significance should not be attached to these relationships. It is readily conceivable that the addition of several pots in any group might still further reduce the margin of difference or even change the present order. For instance, western yellow pine No. 213 is higher than bristlecone pine No. 207, and if western yellow pine No. 213 were omitted, this species would average less than Douglas fir. A preliminary series with a smaller number of plants in 1918 and 1919 placed the species in an order almost the reverse of that of the 1919–1920 test. It is evident that in order to obtain reliable data the experiment should be conducted on a more extensive scale.

TABLE 26.—*Transpiration, and effective water use of different species of trees in relation to accretion in dry weight* [1]

Species, pot No., and age when potted	Dry weight		Transpiration, 1919 and 1920 [3]	Water used per gram of accretion
	Initial [2]	Accretion during two years		
	Grams	*Grams*	*Grams*	*Grams*
Bristlecone pine:				
207 (5 years)	7.66	19.89	8,186	412
208 (5 years)	5.42	13.78	6,465	469
Average 6 plants				440
Western yellow pine:				
204 (3 years)	6.03	30.25	11,219	371
205 (2 years)	2.55	16.69	6,469	388
213 (2 years)	2.87	22.83	9,771	428
Average 9 plants				396
Douglas fir:				
209 (4 years)	8.76	29.06	10,895	375
210 (4 years)	11.07	27.61	10,672	387
Average 6 plants				381
Blue spruce:				
212 (4 years)	7.14	15.51	5,478	353
215 (4 years)	7.83	31.33	11,445	365
Average 6 plants				359

[1] Since each pot contained three plants, all values are for three plants.
[2] Computed from ratio of dry to green weight of similar plants.
[3] Transpiration recorded only for July 1–Oct. 3, 1919, and Mar. 3–Sept. 1, 1920.

Table 27 gives the wilting coefficient for the same four species in two kinds of soil. The plants in the stony clay loam are the same as those used in the transpiration work, with several additions. As is to be expected, the soil to which sand was added has a much lower wilting coefficient than the clay loam. The results, however, indicate no large or consistent differences in the ability of the different species to extract moisture from the soil. This is in accord with the conclusion of Briggs and Shantz (*6*). Korstian (*23*), on the other hand, found the highest sap densities and, hence, the strongest pull on soil moisture in the species which occupy the driest sites. Thus, in Utah juniper osmotic pressures ranged from 15.9 to 28.2 atmospheres, whereas in Engelmann spruce the range was from 10.2 to 19.0 atmospheres. These conclusions are not necessarily in conflict, because Korstian's results were obtained from trees growing under a wide range of conditions and it is not unlikely that juniper and spruce in the same environment would exhibit similar sap densities.

TABLE 27.—*Wilting coefficient of different species of trees in natural and prepared soil*

Species	In stony clay loam [1]			In prepared soil (one-half clay loam and one-half sand)		
	Pots	Plants	Wilting coefficient	Pots	Plants	Wilting coefficient
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
Bristlecone pine	4	10	10.56	2	2	6.35
Western yellow pine	4	8	10.55	5	7	5.80
Douglas fir	4	10	10.30	4	4	6.26
Blue spruce	1	3	10.25	3	3	6.03

[1] The pots in Table 26 form a part of this series.

In the course of a wilting test, interesting reactions of seedlings to the drastic reduction of soil moisture were observed. (Fig. 36.) On August 10, 1920, watering was discontinued in pots of western yellow pine, Douglas fir, bristlecone pine, and blue spruce, which prior to that time had been maintained at a moisture content of about 20 per cent, or approximately 9.5 per cent above the wilting coefficient for the soil in question. The rate of transpiration began to fall soon after,[20] and at the end of a month it was in most cases less than 3 per cent of the original rate. In the meantime the soil moisture had fallen to points varying from 0.2 to 0.5 per cent above the wilting coefficient. During the next two months, transpiration was almost imperceptible; plants of all species showed signs of weakening, as was indicated by change of color and drying of some of the leaves, but they did not have the appearance of wilting. With the approach of snow and cold weather in the latter part of October, all the pots were placed in the greenhouse. A change in mean temperature from 32° to 54° F. brought no appreciable response in transpiration. In order to ascertain whether the plants were really

[20] The gradual decline of transpiration here shown differs from the results of Veihmeyer, who found that in young prune trees the consumption of water was independent of soil moisture as long as it remained above wilting coefficient (*45*).

living, two pots containing western yellow pine were watered on November 13, restoring the average moisture content to 20 per cent. Immediately the transpiration rate shot up to the level maintained before the water supply was cut off, and new shoots appeared the following March. No species other than western yellow pine was watered.

No definite conclusions could be drawn regarding the relative persistence of different species, except that bristlecone pine seemed to surpass all the others. In some cases, the variation among individuals of the same species equaled that between the species. The important fact brought out in this experiment is that all four species

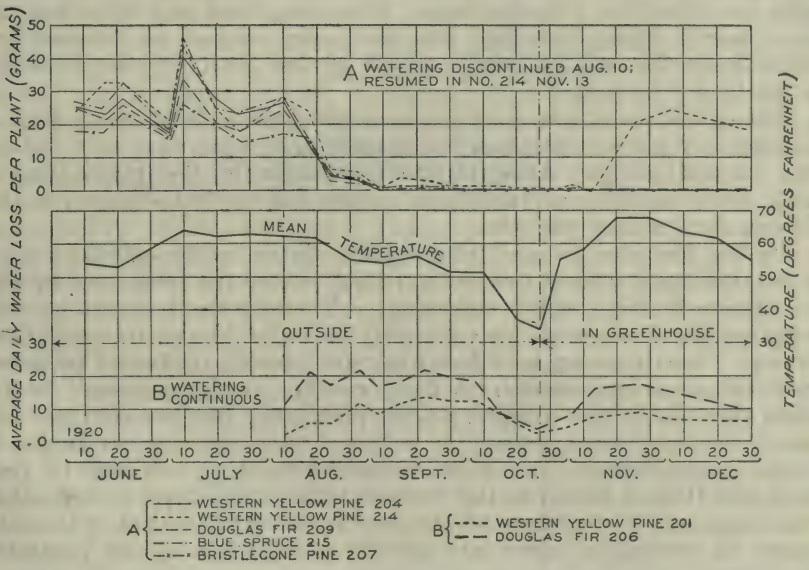

FIGURE 36.—Effect of soil moisture on transpiration, as shown by the behavior of typical pots of each species. All plants were moved from outside to the greenhouse October 27

apparently possess a great capacity for checking transpiration when the water supply is reduced to a dangerously low level.

WINTERKILLING

The generally accepted explanation of winterkilling is that the water in the soil surrounding the roots freezes and becomes unavailable. According to Kihlman (*22*), this condition, known as physiological dryness, takes place when the temperature of the soil water falls to about 34° F. If atmospheric conditions are such as to favor transpiration when the roots are unable to absorb moisture from the soil, the aerial portions of the plant tend to dry out. If this relation continues over a long period, the leaves and even the stems die. Winterkilling is favored, especially on bare ground, by extremely low night temperatures, high winds, and warm sunny days.

In the Southwest conditions causing winterkilling are most prevalent in the western yellow pine zone. In the winter of 1922–23,

groups of western yellow pine saplings 3 to 4 feet high on a steep north slope near the Fort Valley station suffered severely, about 5 per cent of the trees being killed outright. On a gentle southwesterly exposure in the vicinity, the damage was appreciably less. During the same winter, large trees on an entire north hillside suffered to the extent that the leaves turned brown and caused the trees to appear dead. In June, however, practically all the trees took on new foliage. In the winter of 1924–25 saplings on a southerly exposure suffered more than those on a near-by north exposure. It can not be said from the observations made that any exposures are generally worse than others, for other conditions enter too largely into the situation. South slopes, it is true, thaw out more quickly than north slopes, but they are also more subject to evaporation. Sometimes the soil on south slopes in low altitudes may become actually dry in winter.

The piñons and junipers occasionally suffer from winterkilling in their natural environment but usually only when they occur above the normal range. Atmospheric conditions in the piñon-juniper zone favor rapid transpiration in winter, but the soil seldom remains frozen during long periods.

In the Douglas fir and Engelmann spruce zones of this region winterkilling is almost unknown, except where the trees are exposed to extremely high wind movement. Even there it is not certain whether the damage is due primarily to water loss or to mechanical action. Seedlings up to 4 feet high are usually protected by snow. Soil temperatures remain at dangerously low levels much longer than they do in the western yellow pine zone, but the cold air and low wind movement, except on exposed sites, are not conducive to high transpiration. An even temperature, less extreme in heat and cold than is found in the western yellow pine type, is favorable. Seedlings and transplants of Douglas fir in nurseries below the altitudes of continuous snow are usually a total loss if not protected in winter.

In the higher altitudes, exposed situations such as prominent ridges and steep south slopes are occupied almost exclusively by limber pine or bristlecone pine. These situations undoubtedly present severe conditions with respect to winterkilling. Evaporation is high because of high insolation and exposure to dry winds, and yet the night temperatures are low enough to freeze the soil to considerable depths. As shown by the planting experiments to be described, limber pine and bristlecone pine are the only species, with the possible exception of western yellow pine, that can withstand the winters on these sites.

Considered in their native habitats, the species or groups of species may be ranked with respect to liability to winterkilling about as follows: Western yellow pine, junipers, piñon, Douglas fir, spruces, true firs, limber pine, and bristlecone pine. The indications are that if all were subjected to equally trying conditions of frozen soil accompanied by relatively high evaporation, Douglas fir would head the list in liability to winterkilling and would be followed closely by the true firs and spruces and that the pines and junipers would show relatively greater resistance.

Shreve (*41*) reports a form of winterkilling among desert plants which appears to be caused by long periods of freezing temperature,

irrespective of frozen soil or physiological dryness. Thus, he finds that the giant cactus (*Carnegiea gigantea*) succumbs when the temperature remains continuously below 32° F. for more than 18 hours. It is surmised that some of the observed damage in piñon and juniper may be of this nature. Broad-leaved trees, when planted in the western yellow pine zone, are also subject to a form of winter-killing which seems unrelated to soil moisture.

GROWTH PERIODS

During the three years in which climatological records were maintained in the San Francisco Mountains, weekly observations were made on the progress of growth, flowering, and maturing of seed. If all species were to respond equally to the stimulus of heat, one would expect the date of the beginning of growth to recede with altitude, in conformity with the temperature curve. In practice it is difficult to reduce the data on this subject to absolute terms for the purpose of comparison, because conditions vary on different sites and the growth habits of different species and even individuals of the same species are dissimilar. As far as possible, the species are compared on similar exposures and soils. This, however, is not always possible. For example, Engelmann spruce and Douglas fir in this region grow on much lighter soils than those prevailing in the western yellow pine zone. Typical stands of Engelmann spruce are restricted almost entirely to northerly exposures, and limber pine and bristlecone pine prevail on southerly exposures.

The beginning of growth in western yellow pine is marked by rapid elongation of the buds with the first warm days in May. If warm weather continues, the shoots grow steadily until about July 1, when elongation falls off and soon ceases. More frequently, however, the first growth is halted for several weeks by cold weather, and active growth is not resumed until June. Under these circumstances it is often difficult to fix a date for the beginning of active growth. In the pines the new shoots push out rapidly, but the new leaves do not develop until shoot elongation is almost finished. In the spruces and firs, leaves and stems develop simultaneously, the stems elongating rather gradually with the result that growth early in the season is less conspicuous than in the pines.

Table 28 presents, for the purpose of comparison, approximate dates of plant activities in different forest types. According to this table, the beginning of all vegetative activities is retarded with a rise in altitude, but the high-altitude species mature their seed earlier than those in the lower altitudes. In other words, the growing season is shortened at both ends as we ascend. The dates do not attempt to cover the ext me but rather the middle range of each species. In all species growth begins noticeably earlier at the lower than at the upper limits of the range. Opportunities are sometimes afforded for comparing two or more species on the same site. Under these circumstances, the one which normally grows in the coldest climatic zone is usually farthest advanced. Exceptions are limber pine and bristlecone pine, both of which are later than their immediate associates and little, if any, earlier than species of the next lower climatic zone. When found side by side, Douglas fir and white fir are earlier than western yellow pine, but limber

pine is not appreciably earlier except in maturing seed. Engelmann spruce and corkbark fir are both decidedly ahead of bristlecone pine.

TABLE 28.—*Approximate dates of various plant activities in the different forest types*

Plant activity	Western yellow pine	Douglas fir	Limber pine	Aspen
Vegetative buds swelling	May 1–15	May 15–30	May 15–30	May 10–30.
Vegetative buds elongating or opening.	May 15–25	June 1–15	June 5–20	May 20–June 10.
Shoots making rapid growth	June 10–30	June 15–30	June 15–30	
Leaves coming out	June 15–July 30	June 10–20	June 10–20	June 5–15.
Shoot growth ceased [1]	July 1–10			
Staminate buds appearing	May 20–31	June 1–15	June 1–10	
Pollen falling	June 10–20	June 20–30	June 20–30	
Cones full grown	Sept. 15–30	Sept. 5–20	Sept. 5–20	No seed.
Seeds mature	Oct. 1–20	Sept. 10–30	Sept. 10–30	Do.
Leaves falling	Oct. 1–30	Oct. 1–30	Oct. 1–30	Oct. 10–30.
Period of active growth	May 15–Sept. 20	June 1–Sept. 25	June 5–Sept. 10	May 20–Sept. 10.

Plant activity	Bristlecone pine	Corkbark fir	Engelmann spruce
Vegetative buds swelling	June 1–20	June 1–15	June 10–20.
Vegetative buds elongating or opening	June 20–30	June 15–20	June 20–30.
Shoots making rapid growth	July 1–30	June 20–July 15	July 1–20.
Leaves coming out		June 20–30	June 20–30.
Shoot growth ceased [1]			
Staminate buds appearing	July 1–10	June 10–20	June 10–20.
Pollen falling	July 20–Aug. 20	June 20–30	June 25–July 5.
Cones full grown	Sept. 10–20	Sept. 1–20	Sept. 1–20.
Seeds mature	Sept. 20–Oct. 10	Sept. 10–Oct. 1	Sept. 15–Oct. 10.
Leaves falling	Oct. 1–30	Oct. 1–30	Oct. 1–30.
Period of active growth	June 20–Sept. 20	June 15–Sept. 10	June 15–Sept. 10.

[1] No definite data on species other than western yellow pine, but growth is practically over by the end of July, except in aspen.

Observations on the beginning of root growth have been made only on planted specimens at the experiment station. Western yellow pine is later than Douglas fir, blue spruce, and bristlecone pine. All species covered by the observations begin root growth about the time the buds begin to swell, a month or more before the bud scales burst. This fact is of great importance in relation to artificial reforestation. It points to the advantage of early planting in order to give the roots opportunity to begin functioning before new shoots and leaves are put forth.

FREQUENCY OF SEED CROPS

The idea prevails that seed crops are produced at somewhat regular intervals, fixed for each species. No definite periodicity has been observed in the San Francisco Mountains, except that limber pine rarely and bristlecone pine never has been known to fail. The nearest one can come to stating an average figure is to say that limber pine and bristlecone pine bear a good crop of seed nearly every year and the other species every two or three years. The quantity and quality in any year are evidently determined largely by external conditions such as frost and insects. Sometimes climatic effects are local, but at other times they are widespread. In some years western yellow pine has failed, while Douglas fir and Engelmann spruce in the same locality but at higher altitudes have borne prolifically.

In 1923 all species throughout the Southwest appear to have borne a good crop, whereas in 1924 failure was general except for bristlecone pine. In 1918 western yellow pine bore a phenomenal crop over most of the Colorado Plateau and practically throughout Arizona and New Mexico; yet one area within 2 miles of a heavy-yielding district bore only a light crop, and in another locality 15 miles distant there was an almost total failure.

As a rule all species in the San Francisco Mountains fruit sparingly and at infrequent intervals at the upper limits of their range. Observations on this point are confirmed by the absence of dense cone litter usually present in the optimum zones. Western yellow pine, Douglas fir, piñon, and the junipers bear prolific seed crops at the lower limits of their range, except that western yellow pine under these conditions is susceptible to the attack of a cone beetle (*Conopthorus ponderosae*).

RATE OF GROWTH

A comparison of the different species as to rate of growth under natural conditions calls for recognition of variations in site and climate. To determine the relative efficiency of different species as to wood production, they should be grown under the same conditions or at least under conditions in which all factors affecting growth are definitely known. When several species occur in association on the same site, as they do in many places in the Southwest, it is difficult to ascertain how much space each occupies. The site may be optimum for one species and near the minimum for another. Perhaps the fairest comparison of species is to take each in the environment best suited to it.

GROWTH OF INDIVIDUAL TREES

Distinction should be made between the growth of individual trees and the growth of stands. Wide annual growth rings are often due to open spacing and thus may not be an index of production per unit of area. Tables 29 and 30 give the diameter and height growth of average trees of different species in different localities. These figures are not to be regarded as representative of the various national forests but rather as indicating the range of growth under different conditions. It is evident that the so-called woodland species are much slower growing than the saw-timber species. Where western yellow pine and the woodland species come together in the transition zone between their respective types, western yellow pine shows distinct superiority in the rate of growth. In studies of several species on the same site in the transition between the western yellow pine and Douglas fir zones western yellow pine usually has a slight margin over Douglas fir; both exceed limber pine, white fir, and Engelmann spruce but are outstripped by blue spruce up to an age of 140 years. The shade-enduring spruces and firs may attain great age for their size because they have persisted many years in a state of partial suppression during the seedling and sapling stages and recuperated when released. Western yellow pine succumbs more readily to suppression, and therefore trees of this species are more likely to show the expected relation between age and size.

TABLE 29.—*Diameter of various species at different ages in national forests of Arizona and New Mexico*

Species and national forest	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years	180 years	200 years	250 years	300 years
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Emory oak [1] coppice (Coronado)	3.5	7.9	12.3	16.2	19.6	22.6	25.5					
Piñon (Santa Fe)		.9	2.2	3.6	4.8	6.0	7.0	7.8	8.5	9.0		
Utah juniper (Tusayan)	1.2	2.4	3.8	5.2	6.6	8.0	9.3	10.4	11.4	12.4		
Rocky Mountain juniper (Santa Fe)			.9	2.4	3.9	5.3	6.4	7.4	8.0	8.5		
Western yellow pine (Apache) [2]	2.0	4.6	7.4	9.9	12.2	14.4	16.3	18.1	19.7			
Do [3]	1.3	3.4	6.0	9.0	12.0	14.8	17.5	20.0	22.4	24.7	29.8	33.5
Western yellow pine (Tusayan)	1.8	5.2	8.4	11.1	13.2	15.0	16.6	18.0	19.3	20.6	23.8	
Western yellow pine (Prescott)	4.0	11.4	16.8	21.0	24.0	26.2	27.6	28.6	29.4	30.0		
Western yellow pine (Sitgreaves)			11.2	14.7	17.7	20.2	22.1	23.8	25.2	26.4	28.3	
Western yellow pine (Gila)	1.0	6.8	11.2	14.8	17.6	19.8	21.5	22.9	23.8	24.7		
Western yellow pine (Crook)	3.0	8.1	13.6	17.7	20.1	22.6	25.2	26.7	28.4	29.5		
Western yellow pine (Carson)	.7	3.1	6.5	9.3	11.4	13.0	14.3	15.6	16.8	18.1	21.3	24.5
Douglas fir (Apache)	1.4	3.4	6.0	9.0	12.2	15.6	18.8	22.0	25.0	27.7	33.1	37.2
Douglas fir (Crook)	1.9	8.9	13.4	17.2	19.8	22.4	25.0	27.6	30.3	31.9		
Douglas fir (Gila)		5.2	9.0	12.6	15.7	18.7	21.5	24.3	27.2	29.0		
Douglas fir (Carson)		2.3	4.9	7.3	9.6	11.7	13.5	15.3	17.4	20.0	26.0	
White fir (Crook)	1.8	7.0	11.2	14.4	17.8	20.2	22.2					
White fir (Carson)		1.7	4.2	6.9	9.1	10.9	12.2	13.5	14.8	16.2	19.6	
Limber pine (Crook)	1.0	5.0	8.7	11.5	13.7	15.5	17.0	18.3				
Blue spruce (Apache)	1.1	3.8	9.2	14.8	18.4	21.0	22.8					
Engelmann spruce (Crook)		3.0	6.6	10.2	13.1	15.2	16.7	18.3	19.8			
Engelmann spruce (Carson)		2.1	4.9	8.3	10.9	13.1	14.9	16.4	17.7			
Alpine fir (Carson)		2.0	4.9	8.3	10.8	12.8	14.2	15.4	17.1			

[1] Diameters on stump for oak, piñon, and juniper; others 4½ feet above ground.
[2] Western yellow pine type.
[3] Douglas fir—western yellow pine transition.

TABLE 30.—*Height of various species at different ages in different forest types of Arizona and New Mexico*

Species and national forest	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years	180 years	200 years	250 years	300 years
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Emory oak coppice (Coronado)	16	26	32	37	42	45	49					
Piñon (Coronado)	2	6	10	14	16	18	20	22	23	24		
Utah juniper (Coronado)	4	7	10	13	14	15	16	17	18	19		
Rocky Mountain juniper (Coronado)	1	4	7	10	13	15	16	17	17	17		
Western yellow pine (Apache)					49	60	64	69	73	76	82	86
Do.[1]	5	14	26	40	54	66	75	83	90	96	106	111
Western yellow pine (Tusayan)		27					83	90				
Western yellow pine (Carson)	5	21	38	48	53	57	60	62	65	68	75	81
Western yellow pine (Prescott)		31										
Douglas fir (Apache)	4	15	30	45	57	69	79	87	94	101	112	116
Douglas fir (Carson)		16	34	46	54	60	64	68	72	77	88	
White fir (Carson)		8	18	30	41	49	55	60	65	69	76	
Blue spruce (Apache)	4	14	34	58	78	92	104					
Engelmann spruce (Carson)		14	30	49	62	72	78	82	86			
Alpine fir (Carson)		11	27	46	58	69	76	83	88			

[1] Douglas fir—western yellow pine transition.

The wide variation in growth rate of the same species within its normal range affords an interesting subject for investigation. Western yellow pine on the Prescott and Crook National Forests grows much more rapidly than on the Coconino, Tusayan, and Carson. Douglas fir, Engelmann spruce, and white fir all maintain more rapid growth on the Crook and Lincoln than on the Carson. Unfortunately, climatological records are available for only a few of the sites concerned. As a rule, growth of all species is more rapid in the small mountains rising abruptly from the desert in southern Arizona and New Mexico than in the larger mountain masses rising from high plateaus in the central and northern parts of the two States. Indications, including the few available weather records, point to a combination of higher temperature and higher precipitation in corresponding forest types of the southern than of the northern mountains. Another favorable condition in the mountains of southern Arizona and New Mexico is that the soil is nearly everywhere permeable, in contrast with the heavy soils which are more or less common in some sections farther north.

GROWTH OF STANDS

A more adequate expression of growth is furnished by the volume of stands in relation to age. Mean annual growth per acre is readily determined from the age, volume, and area of even-aged, fully stocked stands. Unfortunately, few southwestern forests are even aged, and almost none are fully stocked. Another element of error in calculating mean annual increment is the fact that even though a stand may be fully stocked at the present time, no record is available of the trees which once grew and disappeared. The best stands of all species are rather dense in youth, and there is a gradual thinning through competition as age advances. In western yellow pine this thinning is fairly rapid, but in Engelmann spruce and to a less extent in Douglas fir the struggle for space is prolonged, and stagnation often results. In some Engelmann spruce stands observed at the age of 80 years, there were about 2,000 trees per acre of uniform height, all about 4 inches in diameter and with almost indistinguishable annual rings. When the deadlock is finally broken, the survivors will show a very low rate of growth and a considerable volume, represented by their vanquished rivals, will have been lost.

In the best mature stands as they occur over areas of a section or more, the yields for western yellow pine are about 20,000 board feet, for Douglas fir about 40,000 board feet, and for Engelmann spruce about 30,000 board feet per acre. Average yields, because of understocking, seldom attain more than half of these values. Selected, fully stocked plots of western yellow pine at the age of 200 years often yield as much as 40,000 board feet per acre. Corresponding yields in Douglas fir and Engelmann spruce ran up to 60,000 feet.

In forest practice it is less important to know the relative maximum rate of growth of different species than to know what a certain species may be expected to do under a given set of conditions. The three major commercial species in the Southwest, namely, western yellow pine, Douglas fir, and Engelmann spruce, attain their best development under distinctly different conditions, and only in the transition zones between forest types is there a question as to which

species will make the best growth. In these zones the choice of species calls for a definite knowledge of growth habits and requirements.

CORRELATION BETWEEN PHYSICAL CONDITIONS AND THE DISTRIBUTION OF SPECIES

It may be assumed that in a broad way the distribution of species within a locality is governed by climate, soil, and biotic factors. It is reasonable to suppose that over long periods of time every species growing in a locality should become more or less abundant on all sites congenial to its existence. This, however, does not take into account more or less temporary disturbing elements such as fire, disease, insect or rodent epidemics, and the interference of man, any of which may practically eliminate a species from more or less extensive areas during limited periods of time. There is also a possibility that the absence of a species from a given site may be due to some adverse factor which operates only during the seedling stage, usually the most critical period in the life of a tree. Inability to compete with other species is sometimes thought to account for the absence of certain " intolerant " species such as western yellow pine on sites better suited to more " tolerant " ones, such as spruce. The many clues to these problems furnished by nature have been supplemented by an experiment started in 1917, in which several species of native conifers were planted in each of the forest zones above the woodland.

PLANTING EXPERIMENTS

The species used in the planting experiment were western yellow pine, Douglas fir, limber pine, and bristlecone pone, and also blue spruce which was thought at the time of planting to be Engelmann spruce. The western yellow pine stock was grown in the experiment station nursery from the seed collected on the Coconino National Forest. The Douglas fir and blue spruce came from the Gallinas nursery on the Santa Fe National Forest in northern New Mexico. This forest was also the source of the seed. The limber pine and bristlecone pine were grown at the Fremont laboratory of the Rocky Mountain Forest Experiment Station in Colorado, presumably from Colorado seed. The stock used comprised fully developed nursery-grown transplants from 3 to 5 years old, having well-developed roots from 8 to 12 inches long extending well below any dry surface layer resulting from drought of short duration. Planting was in accordance with the best practice developed at the Southwestern Forest and Range Experiment Station. With the exception of the limber pine-bristlecone pine site, all the planting areas were fenced against grazing animals.

Those who are accustomed to thinking of planting results in terms of the average survival of large numbers will be reluctant to accept conclusions based upon the small numbers of plants employed in this experiment. It should be borne in mind, however, that the main concern here was not the percentage of survival but ability to survive at all. For this purpose five plants properly handled should give more reliable data than several hundred under less careful treatment.

Although survival and size are the only factors capable of quantitative expression, equal significance is attached to the diagnosis of signs of abnormality as observed from time to time.

In all forest types in this region above the woodland, soil moisture is usually abundant below a depth of 5 or 6 inches until the first of June. (Table 21 and figs. 28 and 29.) In the Douglas fir and Engelmann spruce zones the moisture content remains high even through June. With favorable moisture and temperature, growth begins about June 1 in the western yellow pine type and from one to three weeks later in the Douglas fir and the Engelmann spruce types. If the soil becomes too dry later in the summer the new growth is the first to wilt, and if the drought continues the entire plant dies. Young shoots of Douglas fir and blue spruce may wilt when the roots are fairly well supplied with moisture, thus indicating either that these species have a low capacity for absorbing and transporting water or that the young tissues transpire at an excessive rate. Complete drying up during the growing season indicates deficient moisture in the soil. Distinction should be made between summer and winter losses, as the latter usually are not attributable to an actual deficit of soil moisture.

If, with adequate soil moisture, active growth does not begin in June, there is reason to believe that the temperature is too low. Plants suffering from deficient heat during the first growing season usually show a gradual decline, persisting into the second or third season.

Another cause of failure may be deficient light or direct solar radiation, as distinguished from low air temperature. Too much shade, even though accompanied by favorable soil moisture and air temperature, results in slender stems and thin pale leaves. In these cases there may be a question as to whether the deficiency is mainly in light or in heat energy.

It is not known whether all the soils concerned are equally favorable to all species. Enough tests have been made to indicate that there is nothing in any of the soils which is distinctly inimical to any species. If adequately watered, blue spruce and Douglas fir grow well when planted in the heavy western yellow pine soil, and greenhouse tests have shown that western yellow pine seedlings thrive in the light soils of the Douglas fir and Engelmann spruce sites. In this study no failures have been attributed directly to unfavorable soil.

A record of survival from 1918 to 1926 and the condition of the living plants eight years after planting are given in Table 31. In drawing conclusions as to the causes of failure or probabilities of success, the survival record has been supplemented by careful observations of the planted trees and also of native trees on the same areas, where the native trees promised to furnish information bearing on the problem.

TABLE 31.—*Survival of plantings made in 1918 and 1919 in different forest types in the San Francisco Mountains*

Forest type and species	Number of trees planted in—			Number of trees surving in—						Condition in October, 1926
	June, 1918	April, 1918	April, 1919	August, 1918	November, 1918	July, 1919	October, 1920	August, 1924	August, 1926	
Western yellow pine type:										
Western yellow pine		10		9	8	8	8	6		Destroyed by fire in 1924.
Douglas fir		14		8	8	7	2	0	0	
Blue spruce		10		8	6	6	4	1	1	Normal, in shade of western yellow pine;
Limber pine		5		3	2	2	1	0	0	height 2 feet.
Bristlecone pine		5		5	5	4	1	0	0	
				September, 1919	May, 1920	August, 1920	August, 1921	August, 1924	August, 1926	
Douglas fir (not watered)			10	10	10	0	0	0	0	
Douglas fir (watered)			20	20	20	14	6	3	2	Tops dead; height 18 inches.
Blue spruce (not watered)			10	10	10	2	0	0	0	
Blue spruce (watered)			20	20	20	19	18	17	17	All but 4 in good condition; height 3 to 5 feet.
		May, 1918	April, 1919	November, 1918	August, 1920	September, 1921	October, 1923	August, 1924	August, 1926	
Douglas fir type, northwest slope:										
Douglas fir		5		5	5	5	4	3	3	Normal; height 12 to 16 inches.
Blue spruce [1]		5		5	5	5	5	5	5	Tops dead; height 8 to 11 inches.
Western yellow pine		4		4	3	1	0	0	0	
Bristlecone pine		1		1	1	1	0	0	0	
Limber pine		1		1	1	0	0	0	0	
Douglas fir type, aspen bench:										
Douglas fir		4		4	4	4	3	3	3	Normal; height 15 to 20 inches.
Blue spruce		6		6	6	5	5	5	5	Normal, thrifty; height 14 to 18 inches.
Western yellow pine		4		4	4	3	3	2	2	Very slender; height 12 to 20 inches.
Bristlecone pine		2		2	2	2	1	1	1	Normal; height 14 inches.
Limber pine		2		2	2	2	1	1	1	Normal; height 13 inches.

[1] Shaded during greater portion of the day.

TABLE 31.—*Survival of plantings made in 1918 and 1919 in different forest types in the San Francisco Mountains*—Continued

Forest type and species	Number of trees planted in—			Number of trees surving in—						Condition in October, 1926
	June, 1918	June, 1919	November, 1918	August, 1920	November, 1921	July, 1922	October, 1923	July, 1924	August, 1926	
Limber pine - bristlecone pine type:										
Western yellow pine [1]	5		2	2	2		2	2	1	Nornal; height 15 inches.
Douglas fir	3		2	0	0		0	0	0	
Blue spruce	5		4	2	1		1	1	1	Poor condition.
Limber pine	3		2	2	1		1	1	1	Normal; height 19 inches.
Bristlecone pine	3		3	2	2		2	2	2	Normal; height 12 to 20 inches.
Western yellow pine		14		9	8		6	6	5	3 normal; height 12 to 15 inches; 2 with top dying.
Engelmann spruce type, ridge:										
Western yellow pine	6		6	5	2	1	1	0	0	
Douglas fir	5		5	4	2	1	1	1	1	Very slender; height 14 inches.
Blue spruce	7		7	4	0	0	0	0	0	
Limber pine	2		2	2	2	2	2	2	2	Normal; height 11 to 14 inches.
Bristlecone pine	1		1	1	1	1	1	0	0	
Western yellow pine		10		6	6	4	3	0	0	
Engelmann spruce type, northwest slope:										
Western yellow pine	3		3	0	0	0	0	0	0	
Douglas fir	3		3	3	3	2	2	2	2	Poor; height 7 to 8 inches.
Blue spruce	9		9	6	3	2	1	0	0	
Limber pine	3		3	3	2	1	1	1	1	Poor; height 4 inches.
Bristlecone pine	2		2	2	2	2	1	1	1	Poor; height 6 inches.
Western yellow pine		6		5	3	2	0	0	0	

[1] All western yellow pine and limber pine defoliated by sheep in summer 1926.

WESTERN YELLOW PINE

This species has been planted successfully in the western yellow pine zone for several years, and the results shown in Table 31 are regarded as fairly typical.

Western yellow pine was planted on two sites in the Douglas fir zone. It failed completely on the northwest slope, which is the more typical Douglas fir site. Two specimens still persist on the aspen site which, according to soil-temperature records, is slightly warmer than the northwest slope. The slender form of these plants suggests too much shade. On the aspen site, herbaceous vegetation consisting largely of vetch contributes to the shade, as do the aspen trees. On the northwest slope, however, there is less herbaceous vegetation, the shade coming mainly from conifers. The plants receive about three hours of full sunlight in the middle of the day. According to other observations, this is scarcely enough for normal development of western yellow pine, particularly where air temperature is near the minimum. It is evident from Table 21 that moisture is not a factor here or in the zones above this, because the soil at all times contains more moisture than is found in the western yellow pine zone. A native western yellow pine about 40 feet tall occurs some 200 yards distant and 50 feet lower than the aspen site, in an open situation on a steep south slope. Another specimen, taller and apparently older, occurs about 100 feet higher, also on a steep south slope. It is surrounded by aspen but probably started in the open. Both trees have borne scanty crops of cones in the past, and no seedlings are in evidence.

On the limber pine-bristlecone pine site a number of western yellow pines have survived. Partial defoliation each spring furnishes evidence of a severe struggle against adverse winter conditions, a combination of high winds, strong insolation, and low temperature. The wind movement here is second only to that at the timber-line station, and evaporation surpasses that at all the stations above the piñon-juniper type. The soil remains frozen scarcely as long as in the western yellow pine type, the temperatures at the depth of 1 foot being actually higher during January and February. Soil moisture is higher throughout the growing season than in the yellow pine zone. Several of these plants give promise of survival. During the summer of 1926, the new foliage of all the western yellow pines and limber pines on this slope was removed by sheep. Wire inclosures have since been erected.

In the Engelmann spruce zone, western yellow pine planted in the opening on the ridge (station 10B) gave promise of success during the first two years but after that failed rapidly. Growth began here each year about a month later than in the western yellow pine zone, and by the middle of August the new shoots were only from 1 to 2 inches long or about one-half the length of those in the western yellow pine zone.

On this same site, nursery beds were sown to western yellow pine, Engelmann spruce, and bristlecone pine in 1918 and 1919. Both the spruce and bristlecone pine came up so thickly that thinning was necessary; in 1924 the seedlings were from 9 to 12 inches high and were again contending for space. The western yellow pine seeds, which had tested between 60 and 70 per cent, germinated only 5 per

cent in 1918 and 11 per cent in 1919. On May 26, 1924, there were 23 seedlings from about 1,000 seeds sown. They were then, at the age of 4 or 5 years, only 5 or 6 inches tall, although seedlings of the same age in the yellow pine nursery were more than a foot tall. In September, 1927, only 4 of these seedlings were living. They were from 8 to 11 inches tall, very slender, and had short, thin leaves. Bristlecone pine and Engelmann spruce in the same bed were from 11 to 13 inches tall and of good form. In August, 1928, 3 of the western yellow pines were still alive but continued subnormal in development, whereas the bristlecone pine and spruce were in excellent condition.

The behavior of western yellow pine on the northwest slope of the Engelmann spruce zone (station 10A) was exceedingly interesting. The site is in an opening receiving direct sunlight about three hours in the middle of the day in summer. The ground cover is sparse. On July 31, 1918, six weeks after planting, all species except western yellow pine were recorded as growing. On September 9, the buds of western yellow pine had opened, but the new leaves were barely visible. The usual rapid elongation characteristic of this species did not take place. During the next summer a few of the plants grew as much as an inch, but in no case did the needles attain more than half normal length. A year later every plant was dead. Six other yellow pines set out in 1919 reacted as did those of the 1918 planting. Direct seeding with western yellow pine gave equally decisive results. Out of the 200 seeds sown in a screened bed in 1918 only 1 germinated. The following year 6 more came up, and a year later all were dead.

These tests indicate that western yellow pine might be planted successfully in the Douglas fir zone if placed in open situations and on southerly exposures but that it will not succeed on typical Douglas fir or Engelmann spruce sites. Shortness of the growing season and deficient heat during this season are thought to be the chief reasons for failure. The mean maximum air temperature during the period May to September falls from 72.2° F. in the western yellow pine zone to 64.7° in the Douglas fir zone, and the corresponding decline in physiological temperature efficiency is from 3,821 to 2,008. (Table 11.) From the western yellow pine zone (25 per cent shade) to the uppermost natural occurrence of the species, the summer soil temperature at a depth of 1 foot drops 2.7° (Table 12), and the Douglas fir zone shows a further decline of 4.8°. That winter temperatures are not vitally important is indicated by the fact that relatively few losses have occurred during the winter, except on the limber pine-bristlecone pine site where wind dominates the environment. Even on the northwest slope of the Engelmann spruce zone where the soil remains frozen for five months, the planted western yellow pines showed no signs of winterkilling, probably because of the heavy snow blanket.

DOUGLAS FIR

Where not watered, Douglas fir has failed completely in the western yellow pine zone. The soil moisture and high evaporation here as compared with those in the Douglas fir zone and the fact that nearly all the plants died during the dry summer of 1920 point to

drought as the critical factor. The ultimate failure of most of the plants which were irrigated is attributed partly to the fact that the irrigations probably were not frequent enough but mainly to frosts, which have killed back the new growth each spring. If the new shoots are completely killed every year, it is evident that the plant must eventually succumb as the old foliage is shed. If there were enough moisture for Douglas fir in the western yellow pine zone, spring frosts would still in many places prove a limiting factor.

In the Douglas fir zone the planted trees promise to succeed on both sites. In addition to the experimental planting here recorded, several acres have been successfully planted under aspen on near-by sites. The oldest of these plantations was made in 1911. The trees are from 3 to 6 feet tall, somewhat below normal because of damage done by browsing sheep.

As might well be expected, Douglas fir was eliminated from the limber pine-bristlecone pine site during the first year. Wind and high insolation are thought to be the most adverse factors.

Both the northwest slope and the ridge in the Engelmann spruce zone appear to be inhospitable to Douglas fir. Although three plants are still living, they are clearly abnormal. The wide divergence between the northwest spruce slope and the Douglas fir sites in both air and soil temperatures seems to be a decisive factor. Perhaps the most significant difference is in the physiological temperature efficiency, which is 2,008 in the Douglas fir zone and only 994 in the Engelmann spruce. The ridge site of the Engelmann spruce zone is somewhat warmer than the northwest slope (Table 6) but is still much colder than the Douglas fir zone. The advantage of low evaporation is on the side of the spruce sites.

BLUE SPRUCE

Blue spruce, which normally grows under much the same conditions as Douglas fir, has shown itself more resistant to drought, high insolation, and frost than that species. In the western yellow pine zone all the unwatered trees, though showing considerable persistence, died, except one which was planted on the north side of a bushy yellow pine sapling about 8 feet tall, which shaded the seedling during the hottest part of the day. (Fig. 37.) Experiments with western yellow pine in 1919 showed that shading approximately equivalent to that received by this spruce cut down the transpiration by 32 per cent. In August, 1927, this plant was 30 inches tall and of normal appearance. Plants which were irrigated at intervals of about two weeks during the driest seasons nearly all survived, and the tallest were more than 7 feet high in 1927. The relation between watered, unwatered, and shaded plants indicates clearly that moisture is the dominant factor. Blue spruce may live in the shade of trees or buildings in the western yellow pine zone, but to grow at a normal rate it must have more moisture than is usually provided here by precipitation.

On the northwest slope of the Douglas fir zone, the blue spruce were planted along the south edge of the opening where they were shaded the greater part of the day. Though still living in 1926, they were not thrifty and had grown less than the shaded spruce in the

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FIGURE 37.—Blue spruce planted in the shade of a pine sapling. All plants of this species, as well as of Douglas fir, limber pine, and bristlecone pine, planted in the western yellow pine zone, died where not watered or shaded. This specimen of blue spruce, shaded but not watered, was 26 inches tall nine years after planting; others exposed to full sun but watered were from 5 to 7 feet tall

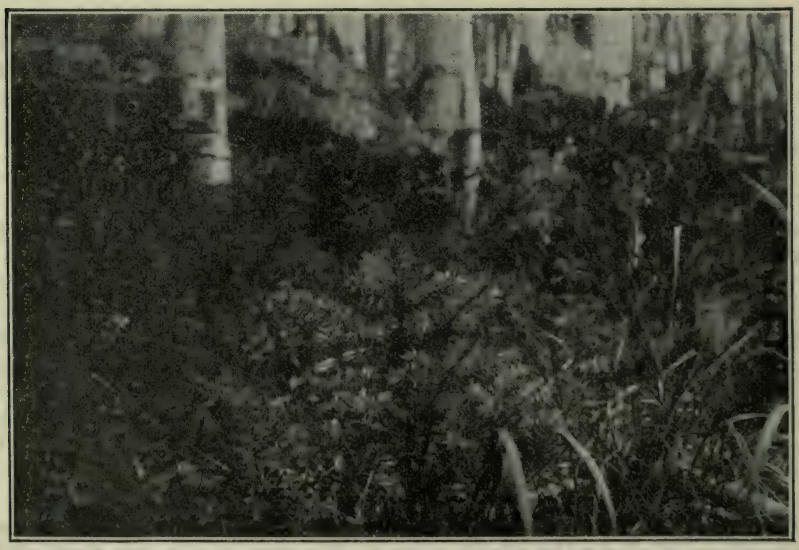

FIGURE 38.—Blue spruce planted under aspen in the Douglas fir zone. Western yellow pine has failed on this site, probably on account of the shade cast by the aspen and the luxuriant herbaceous vegetation. Soil moisture is abundant in all seasons

western yellow pine zone. On the aspen site (fig. 38), where shade is less and soil temperature a little higher, they are thriving but are much smaller than plants which have been watered in the western yellow pine zone. Although blue spruce occurs fairly generally in the Douglas fir zone and in the lower part of the Engelmann spruce zone, its behavior indicates a preference for relatively warm situations with abundant moisture. For reasons not understood, it does not occur naturally in the San Francisco Mountains.

LIMBER PINE AND BRISTLECONE PINE

Limber pine and bristlecone pine are very similar in their habits; both seem to prefer rather open situations, and both are able to grow

FIGURE 39.—Planting site in the limber pine-bristlecone pine zone (steep southwest slope at 10,000 feet elevation). High wind, accompanied by strong insolation, is the critical factor here. Limber pine and bristlecone pine have succeeded; western yellow pine is uncertain; Douglas fir and blue spruce failed

on wind-swept slopes and ridges where other trees fail. (Fig. 39.) Bristlecone pine in the San Francisco Mountains ranges distinctly higher than limber pine. In the western yellow pine zone both species made a promising start, but the summer of 1920 apparently was too dry for them. In the Douglas fir zone, where limber pine grows naturally, both failed on the northwest slope, but since each species was represented by only one plant the test is not conclusive. On the aspen site in 1927, both were growing well, and on the limber pine-bristlecone pine site they were the only species, with the possible exception of western yellow pine, whose success seemed assured. Both were failing on the northwest slope of the Engelmann spruce zone, and this accords with the fact that neither occurs

naturally on sites as cold as this. On the ridge site, which is but slightly above its natural range, limber pine gives promise of becoming established. The death of the solitary bristlecone pine planted here is not significant, being probably due to aftereffects of trampling by horses which were put inside the inclosure by campers. Seedlings raised in a nursery bed are, according to all indications, at home here, as they should be since the species occurs naturally both above and below this site.

ENGELMANN SPRUCE

As has already been explained, Engelmann spruce was not included in the planting experiment but was grown from seed on the ridge site of the Engelmann spruce zone. Here it has made much more vigorous growth than western yellow pine sown in the same bed. Considering the abundance of moisture, the fertility and permeability of the soil, and the adequacy of the sunlight, the only factor which can account for the superiority of Engelmann spruce over western yellow pine on this site is the ability of the spruce to function at low temperatures. On the aspen bench of the Douglas fir planting site Engelmann spruce does not occur naturally, but on the northeast slope it is found in the immature stage in the shelter of larger trees. In a few moist situations it grows on the same site as western yellow pine, but ordinarily there is a gap between the lower limit of the Engelmann spruce and the upper limit of western yellow pine.

Engelmann spruce seed sown in 1918 on the northwest slope of the Engelmann spruce zone germinated, but the seedlings died in the course of one or two years. Their behavior, along with that of natural seedlings discussed elsewhere, is attributed to deficient heat.

NATURAL OCCURRENCE AN INDICATION OF REQUIREMENTS

It may be concluded from these experiments that the natural occurrence of all species in this region very nearly marks their possible range. The theory that the barriers imposed by moisture and temperature can be removed by assisting the tree through the early seedling stage, as when nursery-grown plants are set out, holds only within narrow limits. Where, for instance, western yellow pine is widely scattered on a south slope at high elevation, it is probable that the numbers can be increased by planting if all shade is removed; but it would be unwise to attempt to go above the last natural specimens. Moreover, a stand established under such conditions would not maintain itself by natural reproduction because the seedlings could not bear the reduction of heat which even partial shading by larger trees would bring about. Similarly, although the lower range might be extended slightly by planting, it is doubtful whether a stand established by this means on sites too dry for natural reproduction would survive the exceptional droughts which come periodically.

The suggestion that species are kept within restricted zones by competition is also of limited application. No doubt western yellow pine is driven from optimum Douglas fir sites, and Douglas fir is in turn driven from optimum Engelmann spruce sites by competitors which are better adapted to photosynthesis in low air temperature

and low insolation. But in many openings in both the Douglas fir and Engelmann spruce zones western yellow pine or Douglas fir would temporarily meet no interference. They extend their upper range in places by taking possession of openings, but each soon reaches a limit beyond which it apparently can not go, regardless of competition. When a shade-enduring species pushes downward below its normal range, it is favored rather than retarded by the presence of other species. Thus, Douglas fir, white fir, and limber pine reproduce in the shade of western yellow pine on sites where they could not become established without shelter. It is seldom, however, that they can descend below the upper half of the western yellow pine zone, except on steep north slopes or along watercourses, because soil moisture becomes deficient. Scattered seedlings of white fir, Douglas fir, and limber pine are found under western yellow pine or

FIGURE 40.—Planting site in the Engelmann spruce zone, natural opening, northwest slope, elevation 10,500 feet. All species failed here. Natural seedlings of Engelmann spruce have started several times, only to die in the second or third years

on the north side of rocks or logs on level mesas as much as a thousand feet below their usual range. The fact that on such sites none of these species are found beyond the sapling stage is considered good evidence that they can not assume a place in the upper crown canopy.

TEMPERATURE AND MOISTURE AS LIMITING FACTORS IN NATURAL DISTRIBUTION

In a preliminary report by the writer (*34*) this subject of the factors limiting natural distribution was discussed in considerable detail, and the conclusion was reached that the upper altitudinal limits of each species in this region are determined by low temperature, whereas the lower limits are determined by deficient moisture,

be it low precipitation, excessive evaporation, or unfavorable soil conditions. Subsequent investigations and observations support this conclusion. Anyone may test it for himself merely by observing the conditions under which the various species are found when they occur outside of their usual habitats. Scattered individuals appear in places 1,000 or more feet above or below the zone which the species normally inhabits. Downward extensions are always on northerly aspects, along watercourses, or on other relatively moist sites. Upward extensions, on the other hand, follow ridges or south-facing slopes which receive maximum insolation.

In this manner western yellow pine, which normally occupies altitudes between 7,000 and 8,000 feet in the region about Flagstaff, follows Oak Creek down to an altitude of 4,000 feet and ascends open south slopes on the San Francisco Mountains to 9,300 feet. It has been successfully transplanted under irrigation near Phoenix at an altitude of 1,100 feet. Arizona cypress, whose usual habitat is between 6,000 and 7,000 feet, thrives under irrigation in the hottest valleys of southern Arizona. Douglas fir, probably most sensitive to high insolation of all the species in the region, descends 3,000 feet below its normal range in Oak Creek Canyon. Unlike western yellow pine, however, Douglas fir does not go far above its normal range, probably on account of its inability to withstand high winds and evaporation on open south exposures. White fir and blue spruce, common associates of Douglas fir at altitudes between 8,000 and 9,000 feet, are rather common ornamentals in Albuquerque and other places below an elevation of 5,000 feet. Engelmann spruce is usually at its best at elevations ranging between 10,000 and 11,000 feet, but in many places in moist, sheltered canyon bottoms and on steep north hillsides it goes well below 9,000 feet. With artificial watering it grows well in Flagstaff at 7,000 feet. In the San Francisco Mountains it reaches the highest altitude attained by any tree.

According to the writer's observation, the species which normally occupy high altitudes are unable to grow in low altitudes because of the drought rather than the high temperature prevailing there; they are found at high elevations not because they require low temperature but because they must go where they can find sufficient moisture. Likewise, species which occupy relatively low altitudes are there not because they demand dry soil and dry air but because they must have relatively high temperature and are able to withstand the dry conditions accompanying it. They would respond with greatly increased growth to the copious rainfall of the higher levels, but the temperature accompanying this rainfall is too low for them.

HIGH TEMPERATURE

Bates, (*1*, *2*), as a result of his investigations in Colorado, regards low temperature as the primary limiting factor in the upper ranges but, differing with the writer, believes that high temperature rather than drought is the condition which keeps the high-altitude trees, such as Engelmann spruce and the firs, out of the lower climatic zones. In other words, he regards temperature as the controlling factor both above and below. He attributes the adverse

condition not so much to high air temperature in itself as to local heating of the foliage and, in the case of seedlings, to heating of the stem at the ground line. Toumey and Neethling (*44*) and Hartley (*19*) also have called attention to the injury of conifer seedlings by high surface-soil temperatures, which cause lesions to appear in the stem when the temperature rises above 122° F.

When dealing with leaf injury, it is difficult to make a hard and fast distinction between the effects of heat and drought. High temperature increases evaporation from the soil and also the rate of transpiration. An abundant supply of soil moisture, within the limits of the capacity of the roots to absorb it, enables the plant to withstand a high rate of transpiration without ill effects. When a plant dies during a period of hot, dry weather, it is difficult to say whether heat or drought was the direct cause. But if death can be averted by applying water to the soil it seems logical, in the absence of proof to the contrary, to attribute the trouble to drought.

If lesions or similar injuries appear in the stem when the roots are in contact with moist soil, it seems fair to regard heat as the primary cause. In the Southwest, bare soils fully exposed to the sun not infrequently attain temperatures of 140° F. or more at the surface. This probably explains why, as pointed out by the writer (*34*), survival of western yellow pine seedlings is usually better on spots having a light cover of litter or herbaceous vegetation than on those wholly devoid of cover. Thickness and character of bark more, perhaps, than any other quality determine the ability of a plant to resist heat injury. The "sun scald" common in poplars and other thin-barked trees is not essentially different from the heat lesions described by Bates and Roeser (*3*), Toumey and Neethling (*44*), and Hartley (*19*). In Arizona, conifers beyond the early stage are practically immune unless the soil becomes unusually dry. In nursery practice, western yellow pine has been observed to suffer rather more than the firs and spruces. This may be because pine beds are usually allowed to become drier than fir and spruce beds. A more common trouble in Douglas fir when exposed to the sun, both in the nursery and in plantations, is a drying of the young shoots. Blue spruce and Norway spruce are affected similarly but in less degree, since tender shoots and leaves, though often wilting temporarily, seldom die if the soil is moist. (Fig. 41.) These symptoms are thought to indicate deficient water replacement rather than direct heat injury, because they are alleviated, if not entirely prevented, by copious watering.

While conceding that young seedlings are often killed by high temperatures at the surface of the soil, the writer does not regard this or any other form of heat injury as a common limiting factor in the downward extension of the natural range of forest trees. If high surface temperatures were a limiting factor in the presence of adequate soil moisture, seedlings would overcome it by taking advantage of the shelter offered by logs, stones, shrubs, trees, and other objects which cast a shadow over small areas. Even on the desert, where air temperatures rise to 115° F., there are shaded spots where the surface soil does not become appreciably hotter than the air. It is, however, safe to say that no one has seen spruce, fir, or even pine seedlings springing up under creosote bushes.

LOW TEMPERATURE

Low temperature appears to become a barrier mainly when it involves a deficiency of heat energy during the growing season. This deficiency is usually less apparent in the mean air temperature than in the mean maximum, the duration of high temperatures, or the physiological index of temperature efficiency. (Table 11.) Western yellow pine at the upper limits of its range is poor in both seed production and germination. Observations of other species confirm a similar conclusion as to seed production, but no information on germination is available. Seedlings are less able to function on cold sites than are older trees, because in the seedling stage direct solar radiation is more likely to be intercepted by neighboring trees, herbs, shrubs, logs, rocks, and other objects than it is after the young trees are several feet high. If interference of this sort can be avoided, as when seedlings chance to gain a foothold in temporary openings, a species may live to great age in a temperature zone from which it would otherwise be barred. This is clearly the case with western yellow pine at its extreme upper limits.

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FIGURE 41.—Blue spruce with wilted leader, evidently due to inability of roots to supply water as fast as it is transpired. Norway spruce and Douglas fir planted in the western yellow pine zone behave in the same manner. If the soil is well watered the terminals may wilt in the hot sun but regain their turgidity at night. If the soil is dry, not only the leader, but also the upper shoots, dry up

Reference has already been made to two forms of winterkilling, one attributed to the direct effect of low temperature of long duration and the other to the physiological dryness of frozen soil. It is probable that both these factors may affect the distribution of forest trees in this region under certain conditions, but they are not thought to be of widespread importance as limiting factors. Within the writer's observation, only the woodland species have shown indications of injury from persistent low temperatures. Western yellow pine suffers from what appears to be physiological drought in its middle and lower but rarely in its upper range. In the San Francisco Mountains little winterkilling of any kind occurs above the western yellow pine zone, except on sites exposed to strong winter winds.

As pointed out in the preliminary report on this study (*34*), timber line on well-insolated ridges apparently is due to high winter

winds rather than low temperatures. This opinion is based upon the fact that beyond the upper line of tree growth the spruce continues several hundred feet up the slope in a bushy or prostrate form. The height of these subnormal specimens corresponds to the depth of the snow blanket, and the tips which extend above the snow line are usually stripped of leaves and often bark as well. This extreme condition is attributed more to the mechanical action of the wind than to its drying effect, but this also is evident. True low-temperature timber lines occur on northerly aspects where the spruce ceases abruptly without a transitional bushy or prostrate form and without evidence of winterkilling. Although summer air temperatures here are not appreciably below those on the ridges (Table 6) the insolation and total available heat energy must be less.

On wind-swept burns of northerly aspect in the optimum spruce belt, typical winterkilling occurs in Engelmann spruce, corkbark fir, and bristlecone pine. The trees here consist of scattered saplings, few of which exceed 10 feet in height. Each spring a large proportion of the foliage is brown above snow line on the windward side. Although the reestablishment of the forest is being severely retarded, it is not being prohibited.

The fact that winterkilling is rare in the Engelmann spruce and Douglas fir zones, notwithstanding that the soil remains frozen from three to five months, may give rise to the impression that the species occupying these zones are extremely drought resistant. In the light of the account given in the foregoing paragraph, these species are not immune to winterkilling when exposed to drying conditions in association with frozen soil. Their immunity in stands on well-protected or average sites may be attributed to the absence of high evaporation stresses. Another factor which probably is of considerable importance is that in the higher altitudes the leaves and stems remain covered with snow and ice for several days after each storm, and thus a considerable quantity of this moisture may enter the living tissues.

RANGE OF TEMPERATURE AND MOISTURE WITHIN EACH FOREST ZONE IN THE SOUTHWEST

If, as was concluded in the foregoing pages, temperature and moisture determine the altitudinal range of species, it is desirable to analyze the climate and soil data presented on earlier pages to ascertain where the temperature and moisture limits for each species lie. Before proceeding to a study of the requirements of individual species, however, the range of temperature and moisture conditions in each forest zone will be fixed as definitely as deficient data and complex physical relationships permit. In the following summaries, the extremes of each range are averaged for several years, representing individual stations or groups of stations near the upper and lower limits of each zone in different localities. Summer temperature is regarded as a better index of heat conditions than annual temperature, but the most reliable index of precipitation is considered to be the total for the year, as trees make their growth on moisture stored during the preceding winter as well as on that which falls during the growing season.

For reasons which have been discussed elsewhere in this bulletin, the mean air temperature is not regarded as a good index. It is presented, however, for purposes of comparison in other regions because often this is the only figure given in published temperature records. The mean maximum is considered more indicative of effective temperature, and of still greater significance are the summations showing duration of various temperatures, the product of intensity by duration, and the physiological temperature efficiency, as given in Table 11. Unfortunately, these summations can be used to only a slight extent, because the only series of mountain stations for which they are available is the one in the San Francisco Mountains. In order to bring out more effectively the relation between various types, as was previously explained, temperature summations have been made for the five months (May to September, inclusive), instead of the four months (June to September) employed in computing means of current temperature.

In the following paragraphs the physical conditions as found in each forest zone are summarized. These figures are derived from the various tables appearing in this bulletin but have been modified in a few cases where data at the extremes of a type are lacking or are known to be abnormal. As previously explained, records of air temperature and precipitation have been obtained from many stations throughout Arizona and New Mexico, but temperature summations, soil temperature, soil moisture, and evaporation records are available for only one or a few stations in each forest zone of the San Francisco Mountains during periods of one to three years.

Woodland zone.—Summer temperatures (June–September): Mean 65° to 69° F., mean maximum 79° to 85°, mean soil at 1 foot 64° to 75°, physiological efficiency (total, May–September) 8,412. Moisture: Annual precipitation 12 to 20 inches, evaporation (total, June–September) 30 to 40 inches, available soil moisture at 1 foot (average, May–September, 1918) 2.6 per cent, lowest (September, 1918) −0.4 per cent.

Western yellow pine zone.—Summer temperature (June–September): Mean 59° to 63° F., mean maximum 74° to 80°, soil at 1 foot 56° to 65°, physiological efficiency (total, May–September) 3,822. Moisture: Annual precipitation 18 to 25 inches, evaporation (total, June–September) 18 to 26 inches, available soil moisture at 1 foot (average, May-September, 1918) 3.8 per cent, lowest (September, 1918) −0.5 per cent.

Douglas fir zone.—Summer temperature (June–September): Mean 56° to 58° F., mean maximum 67° to 74°, soil at 1 foot 52° to 54°, physiological efficiency (total, May–September) 2,008. Moisture: Annual precipitation 22 to 34 inches, evaporation (total, June–September) 12 to 16 inches, available soil moisture at 1 foot (average, May–September, 1918) 13.7 per cent, lowest (August, 1918) 7.6 per cent.

Engelmann spruce zone.—Summer temperature (June–September): Mean 50° to 56° F., mean maximum 58° to 68°, soil at 1 foot 44° to 50°, physiological efficiency (total, May–September) 994. Moisture: Annual precipitation 27 to 36 inches, evaporation (total June–September) 10 to 13 inches, available soil moisture at 1 foot (average, May–September, 1918) 13.7 per cent, lowest (September, 1918) 3.8 per cent.

COMPARISON WITH COLORADO CONDITIONS

It is of interest to compare some of the foregoing data with those obtained by Bates (*2*) in Colorado. The most comparable and significant data presented by Bates are in the mean air temperatures for the growing season, which he considers as extending from June 1 to September 10 instead of from June 1 to September 30, the period used in the present investigation. Hence, the average should be slightly higher in Bates's experiments. The ranges of mean temperature for the growing season in Colorado are as follows: Western yellow pine zone, 54° to 64° F.; Douglas fir zone, 54° to 58°; and Engelmann spruce zone, 49° to 56°. In Arizona and New Mexico the corresponding figures for a slightly longer period are 59° to 63°, 56° to 58°, and 50° to 56°. The following are the average of growing-season means at several stations in Colorado: Western yellow pine zone, 59.2°; Douglas fir zone, 56°; and Engelmann spruce zone, 51.6°. Corresponding averages in Arizona and New Mexico are 60.9°, 57°, and 53.8°. The approximate range of summer soil temperature at a depth of 1 foot in the three zones, in the order given above, is, for Colorado, 55° to 60°, 44° to 53°, 40° to 50°; and for Arizona, 56° to 65°, 52° to 54°, and 43° to 53°.

Both air and soil temperatures are consistently lower for corresponding forest zones in Colorado, although the agreement on the whole is as close as can be expected. One might expect to find the same trees occupying cooler sites in Colorado because the precipitation is less than in Arizona and New Mexico. The western yellow pine zone apparently receives nearly the same precipitation in Colorado as in the States to the south, but the Douglas fir and Engelmann spruce zones receive only from 21 to 28 inches, whereas in Arizona and New Mexico they receive from 22 to 36 inches, the average being 26 inches for the Douglas fir and 34 for the Engelmann spruce. There appears to be but little consistent increase in precipitation with altitude above the western yellow pine zone in Colorado. If the firs and spruces require more moisture than western yellow pine, this would force them to seek colder climates where evaporation, transpiration, and probably growth would be less than where higher temperatures prevail.

Another matter deserving consideration is that in widely separated regions different strains of the same species may be involved. It is well known that western yellow pine of the central and southern Rocky Mountains differs markedly in requirements and growth habits from the form of the same tree occurring on the Pacific coast and northern Rocky Mountains. Moreover, differences have been noted between the western yellow pine of Arizona and that of northern New Mexico and Colorado. In northern New Mexico, blue spruce and Engelmann spruce merge into one another so closely that it is often difficult to distinguish one from the other. The same is true of limber pine and Mexican white pine (*Pinus strobiformis*) in certain sections of Arizona and New Mexico. In fact, what is called limber pine in these two States appears to be a different tree from the limber pine of Colorado. Other species present similar problems. Granting that we are dealing with climatic adaptations only, this fact in itself would account for a wide range in the requirements of a species.

INTERDEPENDENCE OF LIMITING FACTORS

As has been repeatedly pointed out in this bulletin, the lines of demarcation in the characteristics of forest types and in physical requirements of species can not be drawn with precision. This is particularly true where indirect rather than direct physical factors are involved. The amount of precipitation, for instance, is at best only a rough measure and may be entirely misleading as to the amount of moisture available, because the proportion of the precipitation which is placed at the disposal of the plants varies greatly with topography and soil. Moreover, the effectiveness of the actually available moisture stored in the soil depends upon a number of other factors such as temperature, evaporation, and soil characteristics. A good illustration of the interdependence of factors is furnished by the Natural Bridge station in Arizona. A record of 30 years shows an average annual precipitation of 23.65 inches, which is slightly above that of typical stations in the western yellow pine zone. Yet western yellow pine occurs sparingly here and is of subnormal growth. The vegetation is more characteristic of the woodland zone. A clue to the cause of this condition is found in the high temperatures which, though not directly injurious, induce a high rate of evaporation. Records, if available, would undoubtedly show evaporation to be so high as to render the precipitation inadequate for western yellow pine. The opposite extreme obtains in the vicinity of Tres Piedras and Elizabethtown, N. Mex., where western yellow pine grows with 2 or 3 inches less than the usual minimum precipitation. In these two localities, the altitude is about 8,500 feet, and the temperature during the growing season is from 2° to 3° F. below the average for western yellow pine. Apparently similar relations occur rather generally in Colorado, where Douglas fir and Engelmann spruce in particular seem to grow with considerably less moisture than in Arizona and New Mexico.

LIMITS OF TEMPERATURE LESS VARIABLE THAN THOSE OF MOISTURE

Temperature as a limiting factor is far more definite than is precipitation. True, this greater definiteness may be partly more apparent than real, since temperature measurements are probably a more accurate expression of heat conditions than precipitation measurements are of moisture conditions. But there is also good reason to consider temperature requirements more fixed because temperature fluctuates less from year to year than does precipitation.

Low temperature appears to be a more rigid barrier than drought. A plant near the lower limits of its range may become established during a series of wet years and when dry years come it may be able to survive at the expense of slow growth until better conditions return. Thus it may succeed in holding on through many years in a zone in which the moisture supply is below the normal minimum for the species. The woodland species, especially, show great capacity for adjusting themselves to drought and thus to a degree surmounting this barrier. The evergreen oaks may still persist on the drier sites as mere shrubs, whereas on adjoining bottom lands they grow to be good-sized trees. Along the lower edges of

the woodland, junipers push out into the drier grassland, gradually decreasing in size until they are not more than a foot or two in height. Western yellow pine exhibits a similar though less extreme dwarfing where it encroaches upon the woodland. Excellent examples of these transitions may be seen along the highway between 15 and 30 miles east of Flagstaff.

If heat instead of moisture is deficient, there appears to be no adequate adjustment. Low temperature results in fewer, smaller, and presumably less active leaves. The processes of nutrition are slowed down until the plant not only can not grow but actually starves to death.

LIMITING FACTOR MINIMA RATHER THAN MAXIMA

Although temperature and precipitation have a more or less definite range in each forest zone, only the lower extremes of the range are regarded as actual limitations. The highest precipitation recorded anywhere in the Southwest is probably not excessive for any tree species common there. Perhaps it would be too sweeping to say that the same is true with regard to temperature, but it is reasonable to believe that all trees would grow better in higher temperatures than prevail in their natural habitats, if these temperatures were accompanied by sufficient rainfall. As it is, the zone of the highest precipitation coincides with that of the lowest temperature and the zone of highest temperature with that of lowest precipitation. In both cases it is the minimum which constitutes the limiting factor.

SPECIFIC REQUIREMENTS OF SPECIES

TEMPERATURE AND MOISTURE REQUIREMENTS

In preceding pages, the main forest types of the Southwest have been depicted in terms of available data on temperature and moisture conditions. The application of these data will now be carried a step further in an attempt to indicate the minimum conditions of temperature and moisture under which each species occurs naturally. In a general way the requirements of a species correspond to those of the forest type in which it occurs, but the two do not always coincide. An endeavor will be made to draw the lines of the species more sharply than type lines, in an effort to indicate conditions under which one may expect normal development rather than bare existence. The difficulty here is the same as in discussing forest types, namely, that temperature and precipitation records are not always a reliable index of heat and moisture conditions. For this reason the study of requirements of species will be based largely on conditions in the San Francisco Mountains and vicinity, where the environment of each climatological station is well known and the conventional temperature and precipitation records are supplemented by data on related factors.

Table 32 gives the minimum limits of temperature and precipitation, as determined in this study, for the principal forest trees in Arizona and New Mexico. If any instance be noted in which the

actual minima are higher or lower than those given in the table, it is likely that the surrounding conditions are not common to this region. The modifying influence of temperature and wind upon moisture and the influence of slope, aspect, and soil upon both heat and moisture have been taken into account, but not sufficiently to cover extreme cases. Where a species is found growing with less precipitation than the minimum here indicated the soil is probably unusually favorable to the absorption and retention of water, or low temperatures and light winds favor low evaporation. Similarly, where the given minimum proves inadequate, associated conditions of soil, temperature, and evaporation may be causing waste or high consumption of water. Available soil moisture supplemented by evaporation would undoubtedly provide a better index than precipitation, but records have not been obtained under sufficiently varied conditions to indicate the minima for species. The same difficulty prevents the use of the various temperature summations, any one of which would be better than averages of mean or maximum intensity as usually recorded.

TABLE 32.—*Minimum temperature and moisture conditions under which various tree species usually grow in northern Arizona*

Species	Temperature, June–September			Precipitation		Available soil moisture at 1 foot, May–September
	Mean air	Mean maximum air	Soil at 1 foot	Annual	May–September	
	°F.	°F.	°F.	*Inches*	*Inches*	*Per cent*
One-seed juniper	65	81	68	12	6	2
Utah juniper	63	79	66	14	7	2.5
Piñon	63	79	66	12	7	2
Alligator juniper	61	78	65	15	8	2.5
Smooth cypress	62	78	67	16	8	3
Western yellow pine	58	70	56	20	9	3.5
Douglas fir	55	62	51	26	12	8
White fir	54	61	50	26	12	8
Blue spruce	53	60	50	24	13	8
Limber pine	54	61	52	24	11	5
Bristlecone pine	52	60	50	28	14	6
Corkbark fir	50	58	46	30	16	8
Engelmann spruce	49	57	45	30	16	8

Optimum conditions of both temperature and precipitation are usually much higher than the lower limits here indicated. Under natural conditions in this region, these optima rarely, if ever, coincide. On the contrary the rule is that approach toward the optimum of one factor leads toward the minimum of the other. High precipitation occurs only at high altitudes where the temperature is too low for rapid growth of most species; the most effective temperatures obtain at middle or low altitudes where the precipitation is too low for rapid growth of most species; the most effective temperatures obtain at middle or low altitudes where the precipitation is too low for rapid growth or even for bare existence. If the lower altitudes provided adequate moisture, with present temperature conditions, the zone of optimum development for each species would probably move downward some 2,000 feet. Such modifications are brought about under artificial conditions where the rainfall in relatively warm zones is supplemented by irrigation.

SOIL REQUIREMENTS

As already stated, the soil variations which affect the distribution of trees in this region are more likely to be physical than chemical. In only a very few instances is there a suggestion of chemical constituents antagonistic to tree growth. One is at the extreme lower limit of tree growth where there may be an accumulation of calcium salts from 1 to 2 feet below the surface, marking the lowest level to which moisture commonly penetrates. In certain areas, rare above the woodland zone, there may be an accumulation of alkali caused by poor drainage. The western yellow pine parks are suggestive of such accumulations, but soil analyses do not confirm their presence. On the contrary, all experimental evidence obtained indicates rather that physical conditions, such as an excess of clay or the presence of hardpan, together with adverse climatic factors, are responsible for these areas.

It may be stated that as a rule conifers in the Southwest reproduce with difficulty in depressions, if the soil is of fine texture. When these sites become adequately stocked, however, they produce the heaviest stands both in point of size of individual trees and in number per acre. Where the soil is very sandy and precipitation light, the rule is reversed as far as reproduction is concerned. Here we find both the best reproduction and the heaviest timber in the valleys. The old silvicultural rule that the densest stocking occurs on poor sites holds in this region for young stands but not for mature and overmature stands. In the western yellow pine zone, particularly, the trees die in patches with the approach of maturity, probably because of deficient moisture in drought periods.

Too little is known about the soil to venture any definite statements regarding soil requirements of species. Existing information indicates that soil limitations which apply under one set of climatic conditions may not apply under another. Observations in the San Francisco Mountains, for example, might lead to the conclusion that spruce and fir grow only on very light soils. In the Wasatch Mountains in Utah, however, these species grow on clay soils. According to Bates (*2*) the soils of the western yellow pine zone in Colorado are everywhere more sandy than those of the Douglas fir and Engelmann spruce zones. In Arizona and New Mexico this relation is reversed in many places.

APPLICATION OF DATA ON FOREST TYPES TO FORESTRY PRACTICE

NEED FOR FURTHER STUDY

The value of definite knowledge as to what conditions different species of forest trees require and in what measure these requirements are met by the various climates and soils in the forest is self-evident. No one will question the theoretical value of such information, but to many it is not clear how it can be applied under the conditions encountered in forestry practice.

One of the first questions to arise is whether the requirements of forest trees can be determined with sufficient accuracy to be of practi-

cal value. Doubts about this point are to be expected when one bears in mind the many possible combinations of soil and climate and the inadequacy of present methods of measuring those aspects of the common physical factors which most directly affect plant growth. For example, air temperature is only an indication of heat conditions as they affect the plant, and precipitation is a still cruder expression of moisture conditions. Notwithstanding these limitations, however, such data as are now available promise to be of much value. Further investigations will undoubtedly result in refinements and may establish new and better criteria for measuring plant requirements. If future efforts are directed along the line of exact experimentation supplemented by systematic observations, always aiming to supplant personal opinion by quantitative measurement, the accomplishments of three or four decades are likely to exceed any estimates that can be made at the present time. In pursuing such a course of experimentation and observation the example set by specialized branches of agriculture where, after centuries of empiricism, real progress has come only with the introduction of experimental methods, is being followed.

MEASUREMENT OF SITE FACTORS

In order to make use of specific data on the requirements of species it is necessary to have equally specific data on sites. If this means long-time instrumental records on each site, the obstacles arising are likely to render the entire scheme impractical. Records over long periods, however, are needed only on typical sites, in sufficient number to constitute a comprehensive physical survey of all forest types. Having permanent records as a framework, it is possible to tie in the measurements at temporary stations in such a way as to furnish good comparative data for local use.

In all climatic records for short periods the data are to be regarded as relative rather than absolute. Relative data are valuable if referred to a reliable standard. More representative records for a locality can be obtained by operating several stations on different sites during a short period than by operating a single station over a longer period.

Thermograph records at five or six stations during one growing season, if referred to a satisfactory control station, should give a fairly good indication of air temperature for a silvicultural unit comprising a single forest type in one locality. The usefulness of such records can be greatly increased by giving due attention to extremes and by employing suitable summation methods.

Soil-temperature readings have great possibilities not only as a measure of soil temperature but also as an index of solar radiation as influenced by cutting. That marked differences in soil temperature prevail under different degrees of crown cover is well illustrated by Table 12, which gives the average soil temperatures at a depth of 1 foot at three stations in the western yellow pine forest. During the months from June to September, 1918, station 1B on the north side of a group of tall trees averaged 8.4° F. colder than station 1C in practically full sunlight, and 2.7° colder than station 1A in about 25 per cent shade. Somewhat smaller though still significant differences were found during the same period in 1919, a year of excep-

tionally heavy rainfall. It is reasonable to assume that plants in different degrees of shade would receive different amounts of heat in approximately the same proportion as the soil. This assumption is borne out by the measurements of leaf temperature cited in the discussion of light requirements.

Although several methods of measuring light intensity are available, each has its disadvantages, and none seem fully to meet the needs of the forester. In general it may be said that the methods which promise to be in some measure adequate are too complex for field use. As has already been pointed out, the form of radiant energy which constitutes the critical factor varies with other conditions. It is surmised that under the conditions prevailing in the Southwest deficient light is to a large extent deficient heat. Soil temperature affords a rough measure of the heating effect of sunlight, and more accurate methods are available if required. It can not be assumed, however, that the measurement of heat energy alone or of any other single form of energy will reveal all that the forester needs to know about light.

Moisture, like temperature, is susceptible of determination on a relative basis by short-period observations. Because of the erratic distribution of precipitation, however, at least two full years' records are needed in each locality, and the stations should not be more than 2 miles apart. The records should be correlated with one and preferably more long-period stations in the same forest zone and locality. Measurements of precipitation should be supplemented by measurements of evaporation, humidity, and soil moisture. Soil examinations, with special reference to depth, physical characteristics, and organic matter, are indispensable in evaluating moisture records.

POSSIBILITIES IN THE USE OF PLANT INDICATORS

Plant indicators can probably be used advantageously to supplement instrumental records. The principle of the plant-indicator method is that plants having the same requirements should grow on the same sites. The presence of one or more members of a group associated on a given site might lead one to expect that others would also find congenial conditions here. This, however, does not always follow, unless their entire range of requirements is the same. When two species are growing side by side, it may be that temperature, for instance, is near the optimum for one and near the minimum for the other. Thus a slight decline in temperature that would not seriously affect the former species might eliminate the latter.

If definite relationships could be established between the requirements of trees and those of common herbs and shrubs, the lower vegetation could often serve as site indicators for certain tree species. Cajander (*9*) has employed this principle in working out the distribution of forest types or sites in Finland where the original forest has been destroyed or changed by artificial forces. In fully stocked stands, he has found a definite relation between rate of growth of trees and the composition of the ground vegetation, and he regards the latter as superior to height growth of the trees as an index of site quality. Preliminary work in the San Francisco Mountains, however, indicates that the problem is not so simple as might be sup-

posed. The herbs which at first thought seem most characteristic of a forest zone are found to have a much wider range than the trees. Thus, the most common grasses of the western yellow pine zone, namely *Festuca arizonica* and *Muhlenbergia montana*, occur in all forest zones above the woodland almost up to timber line. Most of the smaller plants range through at least two forest zones. The possibilities of using such plants as indicators are strengthened by considering development as well as mere occurrence of species. *Festuca arizonica*, for instance, grows 2 or 3 feet tall in the western yellow pine zone, but in the Engelmann spruce zone it is seldom more than 1 foot tall.

Indicators may be negative as well as positive. For example, *Bouteloua gracilis*, which thrives best in the woodland or lower zones, occurs sparingly or is poorly developed on typical western yellow pine sites. From this it may be deduced, and experience in Arizona and New Mexico generally substantiates this conclusion, that areas on which *B. gracilis* attains normal development are not good western yellow pine sites. Generally speaking, the indicator method appears more promising as a means of estimating site quality than of predicting the possible range of trees.

A SCIENTIFIC BASIS FOR SILVICULTURE

Because of the fact that nature has already fitted the species to the sites one is likely to think of the application of a knowledge of forest types mainly in connection with the forestation of denuded or naturally treeless areas. This, however, is but one phase, and at present a minor one. The greatest need for definite data on the requirements of species is in the control of cutting. In marking timber for removal, the forester is continually speculating on the probable effect upon reproduction and upon growth of the remaining trees. But too often he thinks of the method of cutting or silvicultural system as acting directly instead of through its effect on basic physical conditions. Silvicultural studies by observation of what has taken place in old cuttings or by records on sample plots comprising various densities of cover are valuable but inadequate. Even if definite conclusions are reached, in the course of 15 or 20 years it will be found that they hold only for sites similar to those on which the study was conducted. A certain percentage of crown cover on a south exposure will probably give very different results from those obtained with the same cover on a north, east, or west aspect. The result will also vary with altitude. If investigations of this sort were supplemented by instrumental records it would be found that reproduction of various species is more directly related to heat, light, and moisture than to density of crown cover or silvicultural system.

Heat, light, and moisture are all to some extent susceptible of modification by silvicultural operations. Cutting increases the amount of sunlight which reaches the forest floor. The effect manifests itself far less in higher air temperatures than in an increase of heat available for direct absorption by the leaves of seedlings. If temperature conditions are already near the optimum this change may not be important, but if they are near the minimum it should prove highly beneficial. Whether photosynthesis is increased similarly depends on whether or not the light intensity before cutting

was adequate for this activity. In this connection, the possible benefits from increased radiation of the short wave lengths should not be overlooked. In general, cutting brings about a temporary lowering of water consumption by eliminating the root action of the trees which are felled; but on spots exposed to the sun, the surface soil to a depth of 2 or 3 inches dries more rapidly because of increased evaporation.

Accurate measurements of the effects of silvicultural operations upon physical factors involve much painstaking work, but relatively simple measurements and observations may suffice to indicate general trends. The mere fact that a greatly enlarged soil area is exposed to the sun by cutting suggests substantial increases in the amount of heat available for seedlings. This can readily be verified by a few measurements of soil temperature in sunny and shaded situations. Changes in soil moisture can be detected by comparing soil samples from near the stumps of felled trees with samples taken near standing trees. Differences in wind and evaporation become apparent after only a few days' records in a cut-over stand and a neighboring virgin stand, or in several stands representing different degrees of cutting. Since air temperature is affected but little by cutting, definite changes can be detected only by means of rather long records.

EXAMPLES IN SILVICULTURAL PRACTICE

Some applications of data on the requirements of species in silvicultural practice may be illustrated by the following examples:

Western Yellow Pine Type

In the lower portion of the western yellow pine zone, moisture is the dominating factor in natural reproduction of western yellow pine. Seedlings often grow almost under the crowns of older trees, despite shade and root competition. Apparently this is because the shade favors germination by conserving surface soil moisture, and the air is warm enough to enable seedlings to grow with a small amount of direct sunlight. That heat is not deficient in such situations is indicated by the fact that soil temperature at the depth of 1 foot is about the same as in sunny situations in middle altitudes of the zone. Empirical silvicultural methods developed under such conditions would properly stress the importance of protection, with little thought of heat requirements. Such methods applied in the middle or upper part of the zone, however, would not give the best results. Records of air temperature supplemented by measurements of soil temperature in the sun and shade would show that heat conditions here are approaching the minimum and that reproduction is not to be expected in shaded situations.

Douglas Fir Type

In mixed stands of Douglas fir, white fir, western yellow pine, and limber pine, deficient surface moisture, caused by high insolation and attendant evaporation stresses, is the critical factor with the two first-named species, whereas it is deficient heat which limits western

yellow pine. Limber pine tends to occupy an intermediate position, though it is more adaptable to opposite extremes than any of the other species. In stands of this composition it is usually considered desirable to favor Douglas fir and western yellow pine because of their greater commercial value. Silviculturally the balance is very delicate, and the forester's judgment will need to be checked by all the quantitative data available.

It will probably be found that where the mean maximum temperature for the summer months of June–September is below 72° F., western yellow pine seedlings will not thrive in shaded situations. In such places the soil temperature at a depth of 1 foot is likely to be below 57°. These and lower temperatures, however, are congenial to the other species, which will therefore gain the upper hand over western yellow pine, if the latter can survive at all. It will often be a question whether western yellow pine can reproduce to any appreciable extent even under heavy cutting, because of the shade cast by logging débris and undergrowth. If the aim is to get western yellow pine in the openings, the slash should be burned; if Douglas fir is preferred, enough slash should be left to provide moderate shade, but a deep accumulation of litter, which interferes with the early establishment of this species more than with white fir and limber pine, should be avoided. Near the upper limits of the Douglas fir zone, Engelmann spruce and corkbark fir are likely to take possession of the most heavily shaded spots. Here western yellow pine is eliminated by its high heat requirements, and Douglas fir is able to reproduce only in the lightly shaded or open situations. In many places, however, it is barred from sites exposed to full sunlight and wind. Where the mean maximum temperature from June to September is as low as 66°, Douglas fir, and to less extent white fir, is likely to be supplanted by corkbark fir and Engelmann spruce in shaded situations.

Engelmann Spruce Type

In the Engelmann spruce zone, as in the western yellow pine and Douglas fir zones, one sees a reversal of temperature and moisture relations in passing from the lower to the upper altitudes. In the transition from the Douglas fir to the Engelmann spruce zone corkbark fir and Engelmann spruce increase their domination on the cooler sites, and Douglas fir, white fir, and limber pine cling to the more sunny openings. Higher, first Douglas fir and then white fir disappear, but limber pine persists somewhat farther on the open south exposures, where it is joined by bristlecone pine. Toward the upper limit of the zone, corkbark fir begins to drop out. It does not reproduce well in shaded situations where the summer soil temperature falls below 48° F. Bristlecone pine persists to the upper limits of tree growth on ridges and south exposures. Engelmann spruce alone marks the true low-temperature timber line on north exposures. There the summer (June-September) mean maximum temperature is about 55°, and that of the soil in the open at a depth of 1 foot is about 44°. The trees are erect but low growing, and for several hundred feet below timber line there is a marked absence of reproduction. Apparently the present stand started in the open, perhaps after a fire, and now it is only where relatively large breaks occur in

the canopy that reproduction takes place. Thus spruce, which apparently surpasses all other species in this region in its ability to function in low temperature, reaches its final limit, and, as in other species, this limit makes its first appearance among the seedlings that are deprived of a large proportion of the insolation which larger trees are able to appropriate by virtue of their more commanding position.

THE STUDY OF TIMBER-SALE AREAS

Cutting as a means of regulating heat, light, and moisture conditions and thus controlling the composition of the future forest is an effective implement in the hands of the silviculturist. But, without adequate knowledge regarding its proper use, it can become a dangerous implement. It is doubtful whether the problem of cutting can be fully solved by methods of trial and error, which include sample-plot records. In addition to all that can be determined by observation and deduction we need quantitative standards and a measuring stick for determining the kind and amount of change required to bring about the desired results. In timber sales, volume estimates are checked by actual measurements and the minimum selling price is determined by formula. But when it comes to determining proper silvicultural practice to insure restocking and growth, we have no quantitative standards against which the judgment of the forester can be checked. Along with the timber estimates, stumpage appraisal, and logging plans which precede timber sales, there should be an adequate silvicultural study of the proposed cutting area. An important feature of this study should be the best possible appraisal of site factors.

SUMMARY

Seven broad zones of climate and vegetation, determined largely by altitude, are recognized in Arizona and New Mexico. The vertical order, beginning with the lowest, is desert, grassland (including chaparral), woodland, western yellow pine zone, Douglas fir zone, Engelmann spruce zone, and alpine sedge land.

Air temperature generally falls with a rise in altitude. This relation is much more consistent with respect to the maxima than the minima.

Soil temperature also declines with a rise in elevation, in a general way following the course of average air temperature. Aspect, steepness of slope, ground cover, and depth all have an important bearing on soil temperature.

Precipitation, except for local variations, increases directly with altitude. Up to about 9,000 feet in the San Francisco Mountains the increase is rapid and consistent; beyond this altitude there is still an increase, but the rate falls off.

Wind movement apparently increases with altitude, but the relation is to a large extent obscured by forest cover.

Evaporation is increased by wind and also by temperature and low atmospheric humidity. The highest rate of evaporation is recorded on the desert. In the San Francisco Mountains the highest rate was found on an open southwest slope at an altitude of 10,000 feet.

Soil moisture is generally much more abundant in the Douglas fir and Engelmann spruce zones than in the lower vegetational zones.

Soil differences within this region apparently are due more to physical than to chemical characteristics. Other things being equal, the more porous soils are best suited to tree growth.

The natural occurrence of species coincides very closely with the areas meeting their heat and water requirements. It is not considered practical, by planting or otherwise, to extend the permanent range of a species appreciably beyond the range within which the individuals of that species occur or have occurred in the past.

The upper altitudinal range of a species is determined by its ability to function in low temperature, and the low range is determined by its ability to resist drought. In both cases it is the minimum which imposes prohibitive conditions. Except in rare instances where drainage is poor, moisture never becomes excessive for any species in the Southwest. It is possible that the high temperatures of the lower desert may be excessive for some species, but the evidence at hand indicates that all forest trees in this region could descend several thousand feet below their present range if adequate moisture were available.

There appears to be but little difference in the ability of species to extract moisture from dry soil; that is, they all reduce it to the wilting point which in a given soil is about the same for all species. Probably the greatest difference between species lies in their ability to extend their roots and thus enlarge the sphere of their activity. Experiments with blue spruce, Douglas fir, western yellow pine, and limber pine have shown that when the soil moisture approaches the wilting coefficient all reduce transpiration to practically nothing, and that they are able to persist in this state for months at a time.

Because of the fact that temperature decreases while moisture increases with a rise in elevation, the maximum of one factor coincides with the minimum of the other. Therefore, a species which has high temperature requirements must be able to grow with relatively little moisture, and one which has high moisture requirements must be able to grow in low temperature.

Winterkilling and unseasonable frost, though probably responsible for eliminating certain species from certain sites, are not thought to be of general importance as limiting factors in the distribution of species.

Where the temperature is too low for a given species to function normally, the deficiency of heat appears to manifest itself in low maxima rather than in low minima. For this reason the mean maximum is considered a better index than the mean, and growing-season temperatures are more significant than those for the whole year.

Soil rarely acts as a limiting factor in this region except in a local way and in conjunction with climatic limitations. The most important effect of variations in soil is to increase or decrease the amount of moisture available for plant growth. Without ignoring chemical composition and geologic origin, it is probably safe to say that the soil properties with which foresters are mainly concerned in this region are depth, physical composition, and organic content.

Light is not regarded as a limiting factor in the range of trees, but it may have an important bearing on the composition of stands. In the Southwest, where species must occupy zones of low temperature in order to satisfy their moisture requirements, demand for direct insolation is likely to be more a matter of heat than of light for photosynthesis.

It is reasonable to expect that silviculture can be improved by making use of exact quantitative data on temperature, moisture, and soil with reference to the requirements of species and the characteristics of forest zones and sites. This class of data would supplement and refine rather than supplant existing methods. The figures here presented are usable within the limitations which have been indicated.

APPENDIX

METHODS OF STUDY EMPLOYED IN COMPILING SAN FRANCISCO MOUNTAINS RECORDS

AIR TEMPERATURE

Thermographs were checked by maximum and minimum thermometers, exposed in shelters 5 to 7 feet above the ground, or well above ordinary snow depth. At cooperative Weather Bureau stations, the floors of the shelters are usually 4 feet above the ground, and the thermometers are fastened 18 inches above the floor. Experiments carried on during June and July, 1914, in the western yellow pine type showed that thermometers placed at 5½ feet gave minimum temperatures averaging 2.1° lower and maximum temperatures 0.6° higher than those exposed at 8 feet.

The shelters used in this study were all of the standard Weather Bureau type, with the exception of those at timber line, which were wooden boxes constructed with special consideration for ventilation and shelter of instruments against direct exposure to the sun. At the western yellow pine station, the thermographs were checked daily; at the other stations once a week.

When thermographs are in good running order the errors are usually too small to require correction.

Where readings are made only at long intervals, however, it is by no means certain that the error indicated by maximum and minimum thermometers applies to the extremes for each day; in fact, it rarely does. Whether or not it applies must be determined from the relation between errors in the maximum and minimum and from current checks. If, for instance, the errors appear to be due to too great an amplitude in the pen arm, as is the case when the graph is high on the maximum and low on the minimum, these must be scaled down for the more moderate extremes. If, on the other hand, the readings indicate a constant error, due to the pen arm being set too high or too low, a uniform correction should be applied.

SOIL TEMPERATURE

The temperature of the soil was in most cases measured by means of a thermometer suspended in a wooden tube to a depth of 6 inches, or in a ¾-inch metal pipe to depths of 1 and 2 feet. Several wood-encased soil thermometers were used, but they are expensive and have several other disadvantages. During periods of freezing and thawing they tend to heave out of the ground; they are easily broken in replacing; in deep snow, they can be read only with extreme difficulty. Where pipes or tubes are used under such conditions they are allowed to extend 6 inches or a foot above the ground, and the thermometers are taken out for reading, the bulbs being covered with cotton or imbedded in cork to prevent sudden changes. When pipes are exposed to the sun they are wrapped with burlap. With this protection, the errors due to conduction by the metal are negligible.

Tests with thermographs have shown that at depths of 12 to 24 inches, the diurnal fluctuations are too small to require taking into account the difference of two or three hours in the time of observation. Readings at intervals of a week obviously do not give a complete record of the temperature movement, but they are thought to furnish a fair basis for comparison between various stations. Soil thermographs checked by thermometers were used for all records at depths of 6 inches or less.

PRECIPITATION

Rainfall was measured by means of standard 8-inch rain gauges. Snowfall was converted into water equivalent by melting or by weighing. At the mountain stations it was difficult to obtain an accurate catch for a single storm or for a given period. When the stations can be visited only at intervals of a

week or more, this problem is a serious one. Because of drifting, which often completely covers a gauge during a single storm, the catch obtained from an open can is unreliable. Drifting is rare in dense stands of timber, but here a very large proportion of the snow is usually retained by the crowns and blows off several days after the storm, or melts and falls in large masses. All things considered, the most accurate method of measuring winter precipitation in the mountains is to take average samples of the snow on the ground at intervals of a month or less through the winter. Using figures obtained in Utah in 1917 as an index, the total winter evaporation of snow in the Douglas fir and Engelmann spruce types probably amounts to between 2 and 3 inches of water. The loss by melting and run-off is negligible because what little water is formed by melting on the surface is absorbed by the deep mass of snow underneath. Repeated examinations have shown that the ground underneath the snow remains frozen and contains no excess of surface water until the beginning of spring thaws.

The total snowfall for the winter was measured in two ways. One was to leave the overflow can of a rain gauge out all winter. It became filled with snow and was covered to a depth of 2 or 3 feet. As melting proceeded in the spring, the snow settled down until a fairly representative core was contained within the gauge before any appreciable amount of free water was formed. In some instances the gauge burst, but in others it held. The other method employed a snow sampler by means of which an average core of snow as it lay on the ground was extracted and weighed. Two instruments were used—one described by Church (*9a*) and the other by Kadel (*21a*). Both gave essentially the same results; direct comparisons usually agreed within 10 per cent. The average of such results, or the determinations made by the snow sampler alone, have been accepted as giving the best available record of winter precipitation.

EVAPORATION

Evaporation was measured by weekly measurement of the water level in a circular galvanized-iron tank 15 inches in diameter and 8 inches deep placed on the ground in a level position. Measurements were made to the nearest tenth of an inch by means of a rain-gauge stick. At each reading, water was added in sufficient amount to raise the level to 4 inches. A rain gauge placed a few feet distant made it possible to make allowance for rainfall. A screen of ½-inch mesh served to exclude animals and coarse litter, a precaution which experience had proved necessary.

It is recognized that this method is crude, but after considering various methods, it was adopted as the most practical and reliable. The porous cup atmometer is not well adapted to this region because of the prevalence of freezing night temperatures through May and June which is the critical period from the standpoint of evaporation. The Piche evaporimeter is subject to the same limitations. At the time this study was initiated, the Bates inner-cell evaporimeter was in the developmental stage. In its present form this instrument would probably be the most satisfactory available. Greater refinement in the method of measuring the water level in the tanks would have been possible had any of the several improved devices now in common use been employed, but it was felt that in view of the long interval between readings such refinement would be inconsistent with the general standard of accuracy attainable under the conditions encountered in this study.

WIND

Standard United States Weather Bureau anemometers were used for recording velocity. For various reasons no serious attempt was made to maintain continuous records at all the stations. Owing to the fact that the anemometer provides no means of indicating the number of complete revolutions on the dial, the movement in open, windy situations, during a period as long as a week, is usually more or less uncertain. It would no doubt have been possible to improvise a reliable recording device had this been considered of great importance. Instead, check readings were made at 1 or 2 day intervals during limited periods. In all cases, the anemometers were placed at a height of 8 feet above the ground.

HUMIDITY

Psychrometer readings were taken at the control station daily at about 8 a. m. and three times daily during limited periods. The only other daily readings were in the Douglas fir zone on Mount Graham. These were com-

pared with simultaneous readings in the town of Safford, some 6,000 feet below. Two hygrographs were tried out at the control station, but they proved too erratic to be relied upon for the mountain stations with infrequent checks.

SOIL MOISTURE

Samples were obtained by digging to the desired depth with pick and shovel. The stony character of the soil generally encountered in this region precludes the general use of soil augers or soil tubes. Moreover, the method employed, though laborious, rendered it possible to obtain more representative samples than can be had by means of an auger or tube. The practice followed was to dig a hole to the depth of the lowest sample desired. Samples were then taken from two or more walls with a trowel. The outside layer was always removed so as to avoid any effects of drying. Samples were obtained at the following levels: Surface, 1 to 2 inches, 6 inches, 12 inches, and 24 inches. An effort was made to get the samples at these depths rather than a core from 0 to 6 inches, 6 to 12 inches, etc. Each depth was represented by samples from two holes.

The interval between taking samples was usually one month. In normal years, at least, this interval is regarded as sufficiently short, because of the well-defined seasons of drought and rainfall in this region. In the spring of the year the soil is almost invariably saturated from the preceding winter's snow. Drying proceeds gradually, sometimes being interrupted by rain or snow in April and May but rarely in June. June or early July is always the critical period. For this reason it is desirable to obtain a series of samples about the middle of June and again just before the summer rains, which usually begin between July 1 and July 15. Samples in July and August show the penetration of the summer rains, and samples in September and October indicate the severity of the autumnal drought. The usual trend of the moisture graph for depths below 6 inches in this region is as follows: High in April and May, the seasonal minimum about July 1, high in August, and a rather gradual decline in September and October. During the 15 years in which more or less complete records have been kept at the Southwestern Forest and Range Experiment Station, 1919 with its great excess of rainfall is the only year which shows an appreciable departure from the usual. Although a much shorter interval between measurements would be desirable for surface sampling, a good indication of surface moisture is furnished by rainfall and evaporation records.

In order that samples taken at different times and at different stations may be comparable, it is important to give careful attention to the effect of growing vegetation. All samples for each station were taken from sampling spots located in zones of apparently average root activity or, for certain purposes, from two sampling spots, one near the trees and another as far as possible beyond their influence.

The fact that the soils in this region contain greatly varying proportions of gravel and stones caused a perplexing problem to arise. A test in 1919 showed that the coarse material removed from several samples by sifting through a screen of 10 meshes to the inch contained appreciably less moisture than the finer material. In order to insure approximate uniformity in regard to the amount of coarse material present, all samples were run through a screen of 10 meshes to the inch. A finer screen was found unpractical because it became clogged by sticky soils.

WILTING COEFFICIENT

The wax-seal method of Briggs and Shantz was employed. Despite the criticisms of this method, it is thought to express in a fairly satisfactory way the relation between the plant and its available moisture supply. Caldwell has found that the amount of moisture left in the soil at permanent wilting varies greatly with environmental conditions, but that it is greatest when the rate of transpiration is high. It is obvious that plants exposed to a hot, dry atmosphere in bright sunlight will wilt with a higher soil-moisture content than if they are exposed to cool, moist air and are shaded. During protracted periods of cloudy weather, the process of wilting is exceedingly slow. Even in the clear,

dry weather of June and September in the Southwest, permanent wilting is a matter of several days. Plants which wilt in the afternoon sun usually revive at night. After this process has been repeated on three or four successive days, the plants often recuperate when placed in a moist chamber. Moreover, when several individuals of the same species are grown in the same pot some remain fresh after their companions are completely wilted.

From the foregoing, it is evident that wilting is not the result of the conditions prevailing at a given moment or hour, but rather the cumulative effect of varying conditions during several days. It is true that after a plant has approached very near a state of permanent wilting, death may be either hastened or postponed by the atmospheric conditions of a single hour. But transpiration tests with conifers have shown that after the seedlings reach this stage the water loss during an additional day is so small that it will affect the wilting coefficient by less than a tenth of 1 per cent. Greater refinement than this is without meaning.

Oat seedlings were grown in tumblers in an unheated greenhouse. Two or sometimes three tumblers of the same soil were tested side by side. As a rule the individual variation was less than 0.3 per cent. Where it exceeds this figure the results are considered unsatisfactory though not necessarily without value. To those who are accustomed to seeing wilting coefficients carried out to the nearest hundredth of a per cent, the standards described may appear crude. On the other hand, when the many possible sources of discrepancy—the individual variation of plants, the variability of the soils used in the test, and, finally, the probability that the soils on which the tests are made are not truly representative of the series of moisture samples taken through a season—are considered, it would indeed seem remarkable if the experimental error under field conditions proved to be less than 0.3 per cent.

DESCRIPTION OF CLIMATOLOGICAL STATIONS EMPLOYED IN THE SAN FRANCISCO MOUNTAINS STUDY

STATION 1A.—WESTERN YELLOW PINE TYPE, CONTROL STATION

Location.—Fort Valley Branch Station one-fourth of a mile north of station buildings, 9 miles northwest of Fagstaff, Ariz.

Situation.—In the forest one-fourth of a mile northwest from the nearest edge of an open valley 1 to 1½ miles in diameter on a gentle south slope about 40 feet above the floor of the valley. Altitude, 7,300 feet. The station is at the foot of the San Francisco Mountains from which there is a strong flow of cold air at night. The immediate site is in an opening about 100 feet in diameter. Groups of large trees stand to the east, south, and west of the instruments at distances of from 40 to 75 feet. Single trees occur some 60 to 75 feet north and large groups a little farther back.

Forest cover.—Virgin stand of western yellow pine of optimum development for this region, dominants 100 to 115 feet tall.

Ground cover.—Open bunch grass; litter of pine needles.

Soil.—Reddish stony clay loam derived from basalt, clay subsoil; depth 3 to 4 feet.

Instruments.—Air and soil thermograph, maximum and minimum thermometers, soil thermometers, psychrometer, anemometer, evaporation pan, and rain gage. Air thermometers and anemometer placed 8 feet above the ground.

Period of records.—Continuous since 1908, except soil temperatures which began in 1915.

STATION 1B.—WESTERN YELLOW PINE TYPE (SHADE SUBSTATION)

Located 40 feet southwest of station 1A, on the northeast side of a large group of tall trees, shaded after 11 a. m.; pine litter 1 to 2 inches deep; sparse cover of broad-leaved herbs; records of soil temperature 1916 to 1920.

STATION 1C.—WESTERN YELLOW PINE TYPE (SUN SUBSTATION)

Located 60 feet northwest of 1A; receives full sunlight between 9 a. m. and 5 p. m. in summer; soil and ground vegetation the same as at 1A except more grass and a few pine seedlings; records of soil temperature and surface air temperature (shelters placed 4 inches above ground) 1918 to 1919.

STATION 3.—WOODLAND, UTAH JUNIPER

Location.—Ash Fork ranger station, about 1 mile northeast of Ash Fork, Ariz.

Situation.—North side of a large open valley; instruments on a gentle south slope about 25 feet above the floor of the valley. Altitude, 5,100 feet.

Forest cover.—Open stand of Utah juniper; no piñon occurs here.

Ground cover.—Sparse cover of short grass.

Soil.—Reddish stony clay of volcanic origin.

Instruments.—Maximum and minimum thermometers and rain gage permanent equipment; thermograph, 1-foot soil thermometer and evaporation pan temporary. Air thermometers 5 feet above ground.

Period of records.—Air temperature and precipitation 1917 to 1926; soil temperature and evaporation during summer and fall of 1918.

STATION 4.—WOODLAND, PIÑON—JUNIPER

Location.—About 2 miles east of Walnut Canyon ranger station, 11 miles southeast of Flagstaff.

Situation.—On nearly level ground about 75 yards south and 25 feet above the road. Narrow, sparsely wooded valley, 50 yards east. Altitude, 6,500 feet.

Forest cover.—Dense stand of piñon, one-seed, and Utah juniper. Instruments in a natural opening about 30 feet in diameter.

Ground cover.—Short grasses and scattered shrubs.

Soil.—Shallow very stony loam derived from limestone.

Instruments.—Air thermograph, maximum and minimum thermometers, and rain gage. Thermometers 4 to 5 feet above the ground.

Period of records.—Summer, 1918.

STATION 5.—WESTERN YELLOW PINE—WOODLAND TRANSITION

Location.—Walnut Canyon ranger station, 9 miles southeast of Flagstaff.

Situation.—Nearly level, gentle easterly slope, 50 yards from a deep canyon. Altitude, 6,700 feet.

Forest cover.—Open stand of western yellow pine, piñon, and junipers. Instruments not shaded appreciably.

Ground cover.—Short grass and scattered shrubs.

Soil.—Rather light sandy loam derived from sandstone and limestone.

Instruments.—Maximum and minimum thermometers and rain gage permanent equipment; soil thermometer and evaporation pan temporary; air thermometers 5 feet above the ground.

Period of records.—Air temperature and precipitation about eight months of the year since 1914; soil temperature and evaporation during the summer of 1918.

STATION 6.—WESTERN YELLOW PINE TYPE

Location.—Williams, Ariz.

Situation.—Forest supervisor's office, near the middle of town, north hillside about 100 feet above the floor of an open valley to the north and east. Bill Williams Mountain, 9,500 feet high, is about 5 miles south. Altitude, 6,750 feet.

Forest cover.—The original stand of western yellow pine has been cut in the immediate vicinity. Natural young growth of pine and juniper occurs within a half mile to the south and west, and occasional trees remain in the south part of town near where the instruments are located.

Instruments.—Maximum and minimum thermometers and rain gage. Air thermometers 5 feet above ground.

Period of records.—Continuous since 1907.

STATION 7.—WESTERN YELLOW PINE TYPE

Location.—Flagstaff, Ariz.

Situation.—The instruments have been moved several times. They are now in the north part of town on the south brow of a hill about 50 feet above the lower districts. The whole town, however, is in a valley which receives considerable cold air drainage from the San Francisco Mountains 12 miles to the northwest. Altitude, 6,900 feet.

Forest cover.—The town is surrounded by a western yellow pine forest, mostly cut over. Occasional trees remain in various parts of town.

Instruments.—Thermograph, maximum and minimum thermometers, psychrometer, and anemometer. Air thermometers 11 feet above the ground.

Period of records.—Continuous since 1897 (United States Weather Bureau).

STATION 8A.—DOUGLAS FIR TYPE

Location.—Lower slopes of San Francisco Mountains almost on a direct line between the experiment station and the tip of Mount Agassiz.

Situation.—Steep northwest slope, about 75 feet above the bottom of a narrow treeless valley 100 yards to the west. Altitude, 8,900 feet.

Forest cover.—Mixed stand of Douglas fir, corkbark fir, and limber pine. Instruments in a natural opening 40 by 70 feet in diameter, shade at air and soil thermometers about 60 per cent.

Ground cover.—Sparse cover of low herbs.

Soil.—Light sandy loam of good depth but mixed with stones and large bowlders, belonging to the acidic volcanic group. Abundant organic matter in surface 2 to 3 inches.

Instruments.—Maximum and minimum thermometers, air and soil thermographs, soil thermometers, rain gage, and evaporation pan. Air thermometers 8 feet above the ground.

Period of records.—Continuous from 1917 to 1919, inclusive.

STATION 8B.—DOUGLAS FIR TYPE (ASPEN)

Location.—About 100 feet east of station 8A.

Situation.—On a nearly level bench slightly higher than 8A.

Forest cover.—Aspen with scattered young conifers.

Ground cover.—Dense growth of low herbs, such as fern and vetch.

Soil.—Similar to that on 8A but less rocky.

Instruments.—Soil thermometer, rain gage, and evaporation pan.

Period of records.—1918 and 1919.

STATION 8C.—DOUGLAS FIR TYPE, OPEN—UPPER LIMIT OF WESTERN YELLOW PINE

Location.—About 100 yards below 8B.

Situation.—In a narrow opening on a steep south slope.

Forest cover.—One of the last outposts of western yellow pine, apparently marking the upper limit of the species. A lone tree about 40 feet tall occurs here. No western yellow pine seedlings are found in the vicinity, and very few cones are in evidence. Aspen thickets occur at a distance of about 100 feet on the east and west sides.

Ground cover.—Short grass.

Soil.—Similar to 8A but less rocky.

Instruments.—Soil thermometer at a depth of 1 foot.

Period of records.—1919.

STATION 9.—LIMBER PINE—BRISTLECONE PINE

Location.—About 1 mile up the slope from the Douglas fir station.

Situation.—On a steep, bare southwest slope. Altitude, 10,000 feet.

Forest cover.—Scattered specimens of limber pine and bristlecone pine, too far apart to afford shade or wind protection.

Ground cover.—Mixed grasses and occasional bushes.

Soil.—Very light gravelly loam derived from acidic volcanic rocks. Large bowlders appear on the surface here and there.

Instruments.—Maximum and minimum thermometers, thermograph, soil thermometers, rain gauge, evaporation pan, and anemometer. Air thermometers 6 to 7 feet, anemometer 8 feet, above the ground.

Period of records.—1918 and 1919.

STATION 10A.—ENGELMANN SPRUCE TYPE, NORTHWEST SLOPE

Location.—On the west shoulder of Mount Agassiz as seen from the experiment station, about 1 mile above the limber pine–bristlecone pine station.

Situation.—On a steep northwest slope about 100 feet below the top of a long ridge leading directly to the top of Mount Agassiz. Below is a deep canyon. Altitude of station, 10,500 feet.

Forest cover.—Dense stand of mature Engelmann spruce and corkbark fir. Shade about 90 per cent. Instruments in a natural opening about 15 feet in diameter.

Ground cover.—Practically no vegetation occurs under the densest cover. In openings are young spruce and fir, low shrubs, and herbs. Snow lies here until the end of June.

Soil.—Deep sandy loam, mixed with stones and large rocks, many of which appear on the surface. The rocks which are of the acidic type are distinctly granular in contrast to the fine-grained basalt predominating in the western yellow pine type. A leaf litter 1 to 3 inches deep covers the ground, and the upper 2 to 3 inches of soil contains a large amount of organic matter.

Instruments.—Maximum and minimum thermometers, air thermograph, soil thermometers, anemometer, rain gauge, and evaporation pan. Air thermometers 8 feet above the ground; rain gauge and evaporation pan in a near-by opening about 40 feet in diameter.

Period of records.—Continuous 1917 to 1919, inclusive.

STATION 10B.—ENGELMANN SPRUCE TYPE, RIDGE

Location.—Near station 10A.

Situation.—On a ridge about 100 feet above 10A, gentle southwest slope. Altitude 10,500 feet.

Forest cover.—The instruments are in natural opening 90 to 100 feet in diameter, surrounded by dense stands of Engelmann spruce and corkbark fir. The spruce here is generally shorter than at station 10A.

Ground cover.—Open growth of herbaceous plants such as Aquilegia, Dougaldia, Bromus, and Carex. The leaf litter is thinner than on the north slope.

Soil.—About the same as at station 10A, except less undecomposed organic matter.

Instruments.—Maximum and minimum thermometers, air and soil thermographs, soil thermometers, rain gage and evaporation pan. Air thermometers 6 feet above the ground.

Period of records.—1918 and 1919.

STATION 11A.—TIMBER LINE, RIDGE

Location.—Up the ridge from stations 10A and 10B, toward the top of Mount Agassiz.

Situation.—On a ridge about 200 feet wide, steep west slope. Altitude, 11,500 feet.

Forest cover.—Engelmann spruce and bristlecone pine occur in large numbers, but they assume a bushy or prostrate form.

Ground cover.—Sparse growth of Ribes, Polemoneum, Carex, and grasses. In many places the soil apparently is too coarse to support vegetation.

Soil.—Derived from acidic volcanic rocks, mostly ryolite; there are pockets of good soil, but generally it is very coarse and there are large areas of gravel slide.

Instruments.—Maximum and minimum thermometers, air thermograph, soil thermometers, rain gage, evaporation pan, and anemometer (short periods). Air thermometers 7 feet, anemometer 8 feet above the ground.

Period of records.—1917 to 1919, inclusive. Except in 1917 it was often impossible to reach this station between December and April.

STATION 11B.—TIMBER LINE, NORTHWEST SLOPE

Situation.—Over the ridge on the northwest slope about 100 yards from 11A. Altitude, 11,500 feet.

Forest cover.—The station is at the upper edge of a pure stand of Engelmann spruce which here terminates abruptly. The trees are straight and 40 to 50 feet high. The bushy form characteristic of the ridge station is almost absent.

Ground cover.—A few prostrate spruces, Ribes, Polemonium, and Carex.

Soil.—Similar to that at station 11A, very rocky, bordering on a gravel slide.

Instruments.—Maximum and minimum thermometer, thermograph, soil thermometer, anemometer (short periods). Thermometer shelter 7 feet and anemometer 8 feet above ground.

Period of records.—Summer and fall of 1918 and 1919.

LITERATURE CITED

(1) BATES, C. G.
1923. PHYSIOLOGICAL REQUIREMENTS OF ROCKY MOUNTAIN TREES. Jour. Agr. Research 24: 97—164, illus.

(2) ———
1924. FOREST TYPES IN THE CENTRAL ROCKY MOUNTAINS AS AFFECTED BY CLIMATE AND SOIL. U. S. Dept. Agr. Bul. 1233, 152 p., illus.

(3) ——— and ROESER, J., JR.
1924. RELATIVE RESISTANCE OF TREE SEEDLINGS TO EXCESSIVE HEAT. U. S. Dept. Agr. Bul. 1263, 16 p., illus.

(4) ——— and ROESER, J., JR.
1928. LIGHT INTENSITIES REQUIRED FOR GROWTH OF CONIFEROUS SEEDLINGS. Amer. Jour. Bot. 15: 185—194, illus.

(5) BLACKMAN, F. F., and MATTHAEI, G. L. C.
1905. EXPERIMENTAL RESEARCHES IN VEGETABLE ASSIMILATION AND RESPIRATION. IV.—A QUANTITATIVE STUDY OF CARBON-DIOXIDE ASSIMILATION AND LEAF TEMPERATURE IN NATURAL ILLUMINATION. Roy. Soc. [London], Proc., Ser. B 76: 402—460, illus.

(6) BRIGGS, L. J., and SHANTZ, H. L.
1912. THE WILTING COEFFICIENT FOR DIFFERENT PLANTS AND ITS INDIRECT DETERMINATION. U. S. Dept. Agr., Bur. Plant Indus. Bul. 230, 83 p., illus.

(7) BURNS, G. P.
1923. STUDIES IN TOLERANCE OF NEW ENGLAND FOREST TREES. IV.—MINIMUM LIGHT REQUIREMENT REFERRED TO A DEFINITE STANDARD. Vt. Agr. Expt. Sta. Bul. 235, 32 p., illus.

(8) CAJANDER, A. K.
1926. [THE THEORY OF FOREST TYPES.] Acta Forest. Fennica (1925–26) v. 29, 108 p. [English translation. Original article in Finnish.]

(9) CALKINS, H. G.
1925. IN DEFENSE OF BRUSH. Jour. Forestry 23: 30–33.

(9a) CHURCH, J. E., JR.
1912. THE CONSERVATION OF SNOW; ITS DEPENDENCE ON FORESTS AND MOUNTAINS. Sci. Amer. Sup. 74: 152–155, illus.

(10) CLEMENTS, F. E.
1905. RESEARCH METHODS IN ECOLOGY. 334 p., illus. Lincoln, Nebr.

(11) ———
1907. PLANT PHYSIOLOGY AND ECOLOGY. 315 p., illus. New York.

(12) ———
1916. PLANT SUCCESSION; AN ANALYSIS OF THE DEVELOPMENT OF VEGETATION. 512 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 242.)

(13) ———
1920. PLANT INDICATORS: THE RELATION OF PLANT COMMUNITIES TO PROCESSES AND PRACTICE. 388 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 290.)

(14) ——— and WEAVER, J. E.
1924. EXPERIMENTAL VEGETATION; THE RELATION OF CLIMAXES TO CLIMATES. 172 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 355.)

(15) COVILLE, F. V.
1920. THE INFLUENCE OF COLD IN STIMULATING THE GROWTH OF PLANTS. Jour. Agr. Research 20: 151—160, illus.

(16) EHLERS, J. H.
1915. THE TEMPERATURE OF LEAVES OF PINUS IN WINTER. Amer. Jour. Bot. 2: 32—70, illus.

(17) FRICKE, [K.]
1904. "LICHT- UND SCHATTENHOLZARTEN" EIN WISSENSCHAFTLICH NICHT BEGRÜNDETES DOGMA. Centbl. Gesam. Forstw. 30: [315]—325.

(18) GARNER, W. W., and ALLARD, H. A.
1920. EFFECT OF RELATIVE LENGTH OF DAY AND NIGHT AND OTHER FACTORS OF THE ENVIRONMENT ON GROWTH AND REPRODUCTION IN PLANTS. Jour. Agr. Research 18: 553—606, illus.

(19) HARTLEY, C.
1918. STEM LESIONS CAUSED BY EXCESSIVE HEAT. Jour. Agr. Research 14: 595—604, illus.

(20) HESSELMAN, H., and MELIN, E.
1927. STUDIER ÖVER BARRTRÄDSPLANTANS UTVECKLING I RÅHUMUS. I. BETYDELSEN AV KVÄVEMOBILISERINGEN I RÅHUMUSTÄCKET FÖR TALL- OCH GRANPLANTANS FORSTA UTVECKLING. Meddel. Statens Skogsförsöksanst. [Sweden] 23: 337—432, illus.

(21) JAENICKE, A. J., and FOERSTER, M. H.
1915. THE INFLUENCE OF A WESTERN YELLOW PINE FOREST ON THE ACCUMULATION AND MELTING OF SNOW. U. S. Mo. Weather Rev. 43: 115—126, illus.

(21a) KADEL, B. C.
1919. AN IMPROVED FORM OF SNOW SAMPLER. U. S. Mo. Weather Rev. 47: 697, illus.

(22) KIHLMAN, A. O.
1890. PFLANZENBIOLOGISCHE STUDIEN AUS RUSSISCH LAPPLAND. EIN BEITRAG ZUR KENNTNISS DER REGIONALEN GLIEDERUNG AN DER POLAREN WALDGRENZE. 263 p., illus. Helsingfors. (Acta Soc. Fauna et Flora Fennica t. 6, no. 3.)

(23) KORSTIAN, C. F.
1924. DENSITY OF CELL SAP IN RELATION TO ENVIRONMENTAL CONDITIONS IN THE WASATCH MOUNTAINS OF UTAH. Jour. Agr. Research 28: 845—907, illus.

(24) LEHENBAUER, P. A.
1914. GROWTH OF MAIZE SEEDLINGS IN RELATION TO TEMPERATURE. Physiol. Researches 1: 247—288, illus.

(25) LEOPOLD, A.
1924. GRASS, BRUSH, TIMBER AND FIRE IN SOUTHERN ARIZONA. Jour. Forestry 22 (6): 1—10.

(26) LIVINGSTON, B. E., and SHREVE, F.
1921. THE DISTRIBUTION OF VEGETATION IN THE UNITED STATES, AS RELATED TO CLIMATIC CONDITIONS. 590 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 284.)

(27) LOWDERMILK, W. C.
1925. FACTORS AFFECTING REPRODUCTION OF ENGELMANN SPRUCE. Jour. Agr. Research 30: 995–1009.

(28) MATTHAEI, G. L. C.
1905. EXPERIMENTAL RESEARCHES ON VEGETABLE ASSIMILATION AND RESPIRATION. III. ON THE EFFECT OF TEMPERATURE ON CARBON-DIOXID ASSIMILATION. Roy. Soc. [London], Phil. Trans., Ser. B 197: 47—105, illus.

(29) MERRIAM, C. H.
1898. LIFE ZONES AND CROP ZONES OF THE UNITED STATES. U. S. Dept. Agr., Bur. Biol. Survey Bul. 10, 79 p., illus.

(30) MILLER, F. H.
1921. RECLAMATION OF GRASSLANDS BY UTAH JUNIPER ON THE TUSAYAN NATIONAL FOREST, ARIZONA. Jour. Forestry 19: 647—651.

(31) PEARSON, G. A.
1914. A METEOROLOGICAL STUDY OF PARKS AND TIMBERED AREAS IN THE WESTERN YELLOW PINE FORESTS OF ARIZONA AND NEW MEXICO. U. S. Mo. Weather Rev. (1913) 41: 1615—1629, illus.

(32) ———
1920. FACTORS CONTROLLING THE DISTRIBUTION OF FOREST TYPES. Ecology 1: 139–159, 289—308, illus.

(33) ———
1922. SEASONAL DISTRIBUTION OF RAINFALL AS RELATED TO FOREST FIRES IN ARIZONA AND NEW MEXICO. Jour. Forestry 20: 776—779, illus.

(34) ———
1923. NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST. U. S. Dept. Agr. Bul. 1105, 144 p., illus.

(35) ———
1924. STUDIES IN TRANSPIRATION OF CONIFEROUS TREE SEEDLINGS. Ecology 5: 340—347, illus.
(36) ———
1930. LIGHT AND MOISTURE IN FORESTRY. Ecology 11: 145—160, illus.
(37) ROBINSON, H. H.
1913. THE SAN FRANCISCAN VOLCANIC FIELD, ARIZONA. U. S. Geol. Survey Prof. Paper 76, 213 p., illus.
(38) SAMPSON, A. W.
1918. CLIMATE AND PLANT GROWTH IN CERTAIN VEGETATIVE ASSOCIATIONS. U. S. Dept. Agr. Bul. 700, 72 p., illus.
(39) SCHIMPER, A. F. W.
1903. PLANT-GEOGRAPHY UPON A PHYSIOLOGICAL BASIS. (AUTHORIZED ENGLISH TRANSLATION BY WILLIAM R. FISHER.) 839 p., illus. Oxford.
(40) SEELEY, D. A.
1917. RELATION BETWEEN TEMPERATURE AND CROPS. U. S. Mo. Weather Rev. 45: 354—359, illus.
(41) SHREVE, F.
1915. THE VEGETATION OF A DESERT MOUNTAIN RANGE AS CONDITIONED BY CLIMATIC FACTORS. 112 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 217.)
(42) SMITH, A. M.
1909. ON THE INTERNAL TEMPERATURE OF LEAVES IN TROPICAL INSOLATION, WITH SPECIAL REFERENCE TO THE EFFECT OF THEIR COLOUR ON THE TEMPERATURE; ALSO OBSERVATIONS ON THE PERIODICITY OF THE APPEARANCE OF YOUNG COLOURED LEAVES GROWING IN PERADENIYA GARDENS. Ann. Roy. Bot. Gard. Peradeniya 4: [229]–298, illus.
(43) TOUMEY, J. W.
1928. FOUNDATIONS OF SILVICULTURE UPON AN ECOLOGICAL BASIS. v. 1, illus. New York and London.
(44) ——— and NEETHLING, E. J.
1924. INSOLATION, A FACTOR IN NATURAL REGENERATION OF CERTAIN CONIFERS. Yale Univ. School Forestry Bul. 11, 63 p., illus.
(45) VEIHMEYER, F. J.
1927. SOME FACTORS AFFECTING THE IRRIGATION REQUIREMENTS OF DECIDUOUS ORCHARDS. Hilgardia 2: 125–284, illus.
(46) VISHER, S. S.
1924. CLIMATIC LAWS. NINETY GENERALIZATIONS WITH NUMEROUS COROLLARIES AS TO THE GEOGRAPHIC DISTRIBUTION OF TEMPERATURE, WIND MOISTURE, ETC. A SUMMARY OF CLIMATE. 96 p., illus. New York and London.
(47) WHERRY, E. T.
1920. SOIL ACIDITY AND A FIELD METHOD FOR ITS MEASUREMENT. Ecology 1: 160–173, illus.
(48) WIESNER, J.
1895. UNTERSUCHUNGEN ÜBER DEN LICHTGENUSS DER PFLANZEN MIT RÜCKSICHT AUF DIE VEGETATION VON VIEN, CAIRO UND BUITENZORG (JAVA). (PHOTOMETRISCHE UNTERSUCHUNGEN AUF PFLANZEN-PHYSIOLOGISCHEN GEBIETE.) (Zweite Abhandlung). Sitzber. Akad. Wiss. Wien, Math. Naturw. Kl. Abt. 1, Bd. 104: 605–711, illus.
(49) ———
1907. DER LICHTGENUSS DER PFLANZEN; PHOTOMETRISCHE UND PHYSIOLOGISCHE UNTERSUCHUNGEN MIT BESONDERER RÜCKSICHTNAHME AUF LEBENSWEISE, GEOGRAPHISCHE VERBREITUNG UND KULTUR DER PFLANZEN. 322 p., illus. Leipzig.

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UNITED STATES DEPARTMENT OF AGRICULTURE
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WOOD-LIQUID RELATIONS

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CONTENTS

	Page		Page
Introduction	1	Dynamics	15
The structure of wood	3	Impregnation by pressure	15
Softwoods	3	Diffusion caused by differences in moisture content	22
Hardwoods	4	Movement of liquid above the fiber-saturation point	24
Dimensions of wood elements	5	Conclusions	31
Statics	5	Summary	32
Absorption in general	6	Literature cited	32
Absorption of water	6		
Absorption of liquids other than water	14		

INTRODUCTION

Substantially every important property of wood is affected by the presence of some liquid, in one form or another, that is normally in contact with and usually distributed through the wood under the conditions of its commercial use. It seems unnecessary, therefore, to debate the practical importance of fundamental studies of the relations between wood and liquids or to catalogue the instances where information gained from such studies has been of direct practical service. In justification of investigative work of this kind, it should be sufficient merely to point out that the many important practical problems in connection with the drying and the impregnation of wood, the shrinkage of wood, and the numerous uses of wood in which liquids affect the properties seriously, all have their origins in the fundamental relations between wood and liquids.

A large amount of general information on this subject has been obtained from observation of the practical problems involved both

[1] The difficult problem presented by the movement of moisture in wood, which has been unsolved for years, required the best thought of specialists and many points of view, and successful and efficient work demanded close coordination of the efforts of several investigators. The moisture committee of the Forest Products Laboratory was formed to obtain such coordination within the laboratory. The personnel of the committee has included: E. Bateman, F. L. Browne, M. E. Dunlap, L. F. Hawley (chairman), A. Koehler, W. K. Loughborough, A. J. Stamm, R. Thelen, H. D. Tiemann, and F. Tuttle. The wide and varied experience of the members has supplied a comprehensive foundation for the investigative and analytical work of the moisture committee and has therefore contributed largely to this initial report. The subcommittee on publication, Messrs. Bateman, Loughborough (chairman), and Tiemann, has been of special assistance in the study of the literature and in the preparation of the report itself. The author is pleased to acknowledge his indebtedness to his associates.

[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

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in using wood and in preparing it for use, and from extensive experimentation in these problems. There is also available a considerable quantity of fragmentary data on the more fundamental aspects of wood-liquid relations. Besides these sources of information there are many studies of phenomena of the same kind occurring between liquids and substances other than wood, and also much information on the minute structure of the material, a subject prerequisite to any adequate treatment of wood-liquid relations.

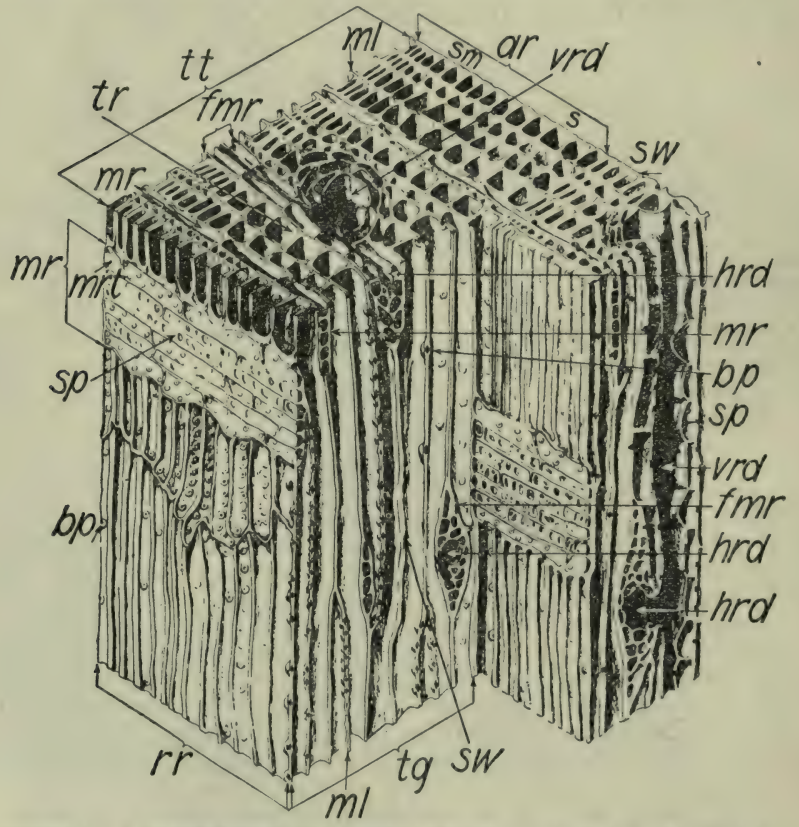

FIGURE 1.—A magnified block of a typical softwood: *ar*, Annual growth ring; *bp*, bordered pit; *fmr*, fusiform wood ray; *hrd*, horizontal resin canal or duct; *ml*, middle lamella; *mr*, wood ray; *mrt*, wood ray tracheid; *rr*, radial surface; *s*, spring wood; *sm*, summer wood; *sp*, simple pit; *sw*, secondary wall; *tg*, tangential surface; *tr*, tracheid; *tt*, transverse surface; *vrd*, vertical resin canal or duct

The primary purpose of this bulletin is to summarize the present knowledge of wood-liquid relations and to prepare the way for a series of publications reporting experimental research on various parts of the general problem. The most significant portions of the available information about wood-liquid relations and wood structure will be included in this presentation of the subject and will be correlated as far as possible by means of the general physical laws applicable.

THE STRUCTURE OF WOOD

SOFTWOODS

Perhaps the best way to show the general structure of wood is by means of enlarged and somewhat idealized drawings of specimen blocks of wood, as shown in Figures 1 and 2. Figure 1 represents a

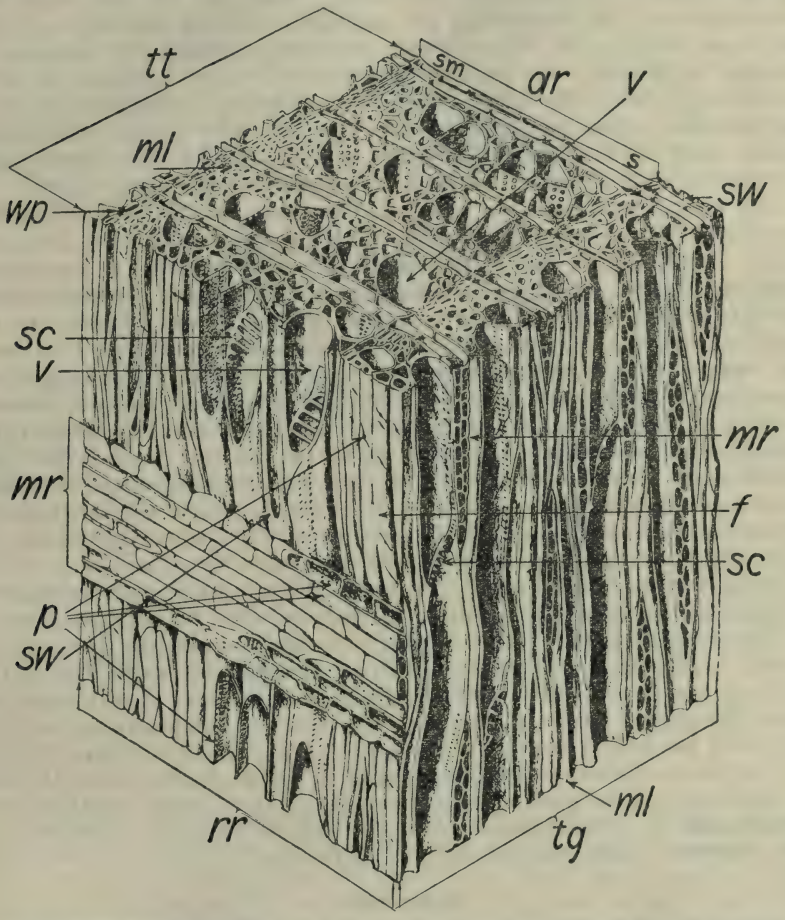

FIGURE 2.—A magnified block of a typical hardwood: *ar*, Annual growth ring; *f*, fiber; *ml*, middle lamella; *mr*, wood ray; *p*, pit; *rr*, radial surface; *s*, spring wood; *sc*, scalariform perforation between vessels; *sm*, summer wood; *sw*, secondary wall; *tg*, tangential surface; *tt*, transverse surface; *v*, vessel or pore; *wp*, wood parenchyma

block of wood, one-fourtieth of an inch on the longer edges, of northern white pine [3] (*Pinus strobus*), which may be considered typical of the softwoods (gymnosperms). The vertical direction in the block represents the vertical direction in the tree from which the block was cut. Since most of the structural elements of the wood

[3] The names of species of wood appearing in this bulletin, other than unverifiable quoted ones, are the standard common names given in the Check List of the Forest Trees of the United States (25).

lie in this direction, it is commonly called longitudinal. The direction represented by the line *ar*, from the bark of the tree to the pith, is called the radial direction. The third direction, represented by the line *tg*, at right angles to the other two, is called tangential.

The main part of the block in Figure 1 is made up of the walls of a series of longitudinal (vertical) cells, *tr*. These are called fibers or, in stricter terminology, tracheids. The end of one series of tracheids and the beginning of another is shown halfway up the left side surface, *rr*. Contiguous tracheids possess in common a median wall layer, the middle lamella, *ml*, which appears to be a cementing layer. The other tubular longitudinal spaces, larger than the cavities in the tracheids, are the vertical resin canals (sometimes called resin ducts), *vrd*. These are surrounded by specialized cells, shorter than the tracheids, which are capable of secreting resin.

The radial structures *mr* are called wood rays. The cells composing them, which are much shorter than the tracheids, are called ray cells. Some of the radial bands of ray cells contain a horizontal resin canal, *hrd*, which communicates directly with a vertical canal, as shown near the lower right corner of the block. There are no main structural elements leading in a tangential direction, but there are means of communication between the tracheids in the tangential direction, the bordered pits, *bp*. Further communication by means of simple pits (*sp*) exists between the tracheids and the wood rays. Bordered pits are thin, circular spots in the cell wall, called pit membranes, over which the unthinned wall extends in a domelike formation that is open at the top. In a simple pit, on the other hand, the unthinned wall does not project over the thinned portion. A pit may be bordered on one side and simple on the other.

Some tracheids are larger in cross section and have relatively thinner walls than others. The large tracheids, which are formed in the earlier part of the season's growth, make up the spring wood, *s*. The later growth of thicker walled tracheids forms the summer wood, *sm*. The spring wood and summer wood together form the annual growth ring, *ar*. The growth bands can usually be seen with the naked eye in the cross section of a piece of wood.

The other softwoods have a general structure very similar to that of northern white pine. Some have larger and some smaller resin canals, and in others these canals are wholly lacking. Aside from this, however, there are no major differences.

HARDWOODS

The hardwoods (angiosperms) as a class, on the other hand, have some major features distinguishing them from the softwoods. These are shown in Figure 2, which represents a cube of yellow poplar (*Liriodendron tulipifera*) of the same over-all size as the block in Figure 1. In addition to the fibers like *f*, which have a purely mechanical function, the hardwoods possess characteristic longitudinal structures of prominence, the vessels or ducts *v*, which in a cross section are called pores. Vessels are composite structures made up of segments or large cells arranged in rows that are vertical in the tree trunk. The vessel segments are shorter and much larger in diameter than the fibers around them, and besides their cavities are joined end to end, instead of side to side, through relatively

large openings, *sc*. The hardwood fibers are generally shorter and smaller in diameter than the softwood tracheids. The pits *p* in the fibers of the hardwoods are much smaller and less numerous and hence less conspicuous than those in the tracheids of the softwoods.

Although the hardwoods may or may not have larger and more thinly walled fibrous tissue in the spring wood than in the summer wood, in many species the spring wood is characterized by the presence of pores much larger than those found in the summer wood. Such hardwoods are known as ring-porous woods. In others, the diffuse-porous woods, the pores are more nearly the same size and are fairly evenly distributed through the annual growth ring. The middle lamella, *ml*, the annual growth rings, *ar*, and the wood rays, *mr*, of the hardwoods are similar to those of the softwoods, although the wood rays are larger.

DIMENSIONS OF WOOD ELEMENTS

The average length of the tracheids in softwoods may vary from 1.5 to 8 mm., and the inside diameter from 0.005 to 0.05 mm. The ends of longitudinally adjacent tracheids overlap from one-tenth to one-fourth of their length, and the bordered pits usually are most abundant in the overlapping portions. In the hardwoods the fibers average about 1 mm. in length, and the range in the diameter of the cell lumina is from about 0.003 mm. for the smaller fibers to approximately 0.4 mm. for the larger vessels. In addition to these details of structure, which are visible under the microscope, it has recently been shown (*21*)[4] that there are openings extending from tracheid to tracheid, which are probably through the membranes of the pits, of unknown shape but with effective diameters (the diameters of true circles having the same effect) as follows:

Range in maximum diameters of five species: 68mμ to 184mμ.[5]

Range in average diameters of two species: 11mμ to 23mμ.

These diameters apply definitely to softwoods only, although it is likely that the pit pores of hardwoods also fall within the same limits.

STATICS

The static relationships of wood-liquid systems are of primary importance, since they control the equilibrium conditions that in turn govern the absorption of liquids by wood and thus not only determine the amount of variation in the physical properties affected by the presence of liquids but also influence the dynamic relationships. In fact many of the dynamic changes are due directly to lack of equilibrium in the static relationships.

Accurate details concerning the static relations between wood and liquids are largely wanting. This situation comes partly from lack of proper investigations and partly from difficulties in distinguishing between the effects caused solely by the wood substance and the modifications of these effects by the complex wood structure. In all of the following discussion of statics, it will be necessary to consider first the theoretical relations between the liquids and the

[4] Italic numbers in parentheses refer to Literature Cited, p. 32.

[5] The Greek letter mu (μ) represents one-millionth part of a meter; a millimicron (mμ) is one-thousandth of a micron.

wood substance and then the possible effects of structure. For simplicity it will also be necessary to consider the equilibriums of wood substance as a whole, without any attempt to distinguish between different parts.

ABSORPTION IN GENERAL

The static relations between wood and liquids considered here belong to the general class of phenomena grouped under the term "absorption." Various other terms, such as "adsorption," "sorption," "imbibition," and "solid solution," have been used to differentiate various types of absorption from the standpoint either of the gross effects or of the mechanism by which the effects are obtained. This study is not concerned with such differentiation; the matter is largely controversial, and there is nothing to be gained by including a discussion of it in this attempt to correlate the absorption effects of wood. On the other hand, the general laws governing the similar absorption effects of other materials will be of value. This bulletin will therefore use the general term "absorption" in referring to the static relations between wood and liquids.

ABSORPTION OF WATER

From the commercial standpoint the absorption of water by wood substance is more important than that of other liquids. Further, the absorption effects of water are greater, and there is more information available on such absorption. This bulletin will therefore take up water absorption first and will then describe the effects of other liquids through comparison with those of water. The absorption of water by wood belongs to the general class of absorptions of liquids by elastic jellies and is almost exactly analogous to the absorptions of water by various cellulosic fibrous materials. These absorptions are characterized by heat of absorption, swelling of the fibrous material, decrease in the vapor pressure of the water absorbed, various changes in physical properties of the fibers, and a comparatively low limit for the water absorbed.

HEAT OF ABSORPTION

The heat given off during the absorption of water by wood is a measure of the strength of the combination and bears a quantitative relationship to the other measures of energy change. Dunlap [6] has determined the total heat of absorption of water by wood at 0° C., finding that for several species there is a range from 14.6 to 19.6 calories per gram of wood. Rosenbohm (*15*) obtained 20.8 calories per gram for the heat of wetting of cotton cellulose by water. Volbehr (*31*) has also determined the heat of absorption of different amounts of water by wood, from 2 per cent up to complete saturation, as shown in Figure 3. Katz (*4*) has shown that cotton cellulose gives a very similar curve.

SWELLING OF WOOD

The amount of swelling of wood substance that accompanies the absorption of water has never been determined with any degree of

[6] DUNLAP, F. HEAT OF ABSORPTION OF WATER IN WOOD. Unpublished report. 1913.

completeness or accuracy. The only direct known information on the subject consists of a few measurements by Roth (*16*), who found that the cell wall in microsections of longleaf pine and of northern white pine decreased in thickness during drying 15 to 31 per cent of the thickness when wet. It is probable that such wide variation is due to lack of control of the dryness during the measurements, since the publication does not mention this control. The only indirect quantitative information available is that obtained from the specific gravities of wood substance and water, together with the amount of water absorbed during swelling. The specific gravity of wood substance is about 1.52, and if during swelling the wood substance absorbs (as will be seen later in this bulletin) about 29 per

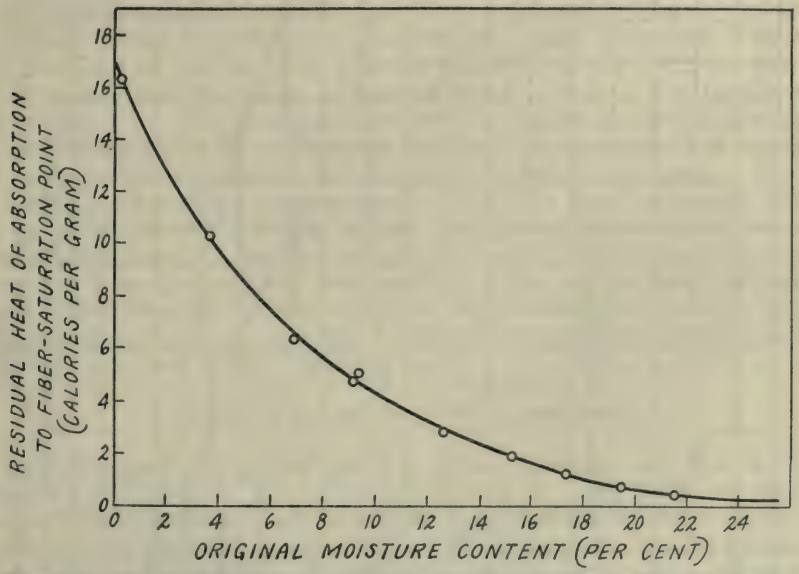

FIGURE 3.—The relation between change in original moisture content and residual heat of absorption for pine-wood flour as the moisture content increases to the fiber-saturation point

cent by weight of water having a specific gravity of 1 the volume of the swollen wood should be 144.1 per cent that of the original dry wood:

$$\frac{\frac{1}{1.52}+\frac{0.29}{1.00}}{\frac{1}{1.52}}=1.441$$

This computation involves the assumptions that there is no compression of the water during the absorption and that there are no preexistent cavities occupied by the absorbed water (*22*), which assumptions are only approximately correct. A swelling of 44.1 per cent of the dry volume is the same as a shrinkage of 30.6 per cent of the green volume, and this value thus corresponds to the upper figures given by Roth.

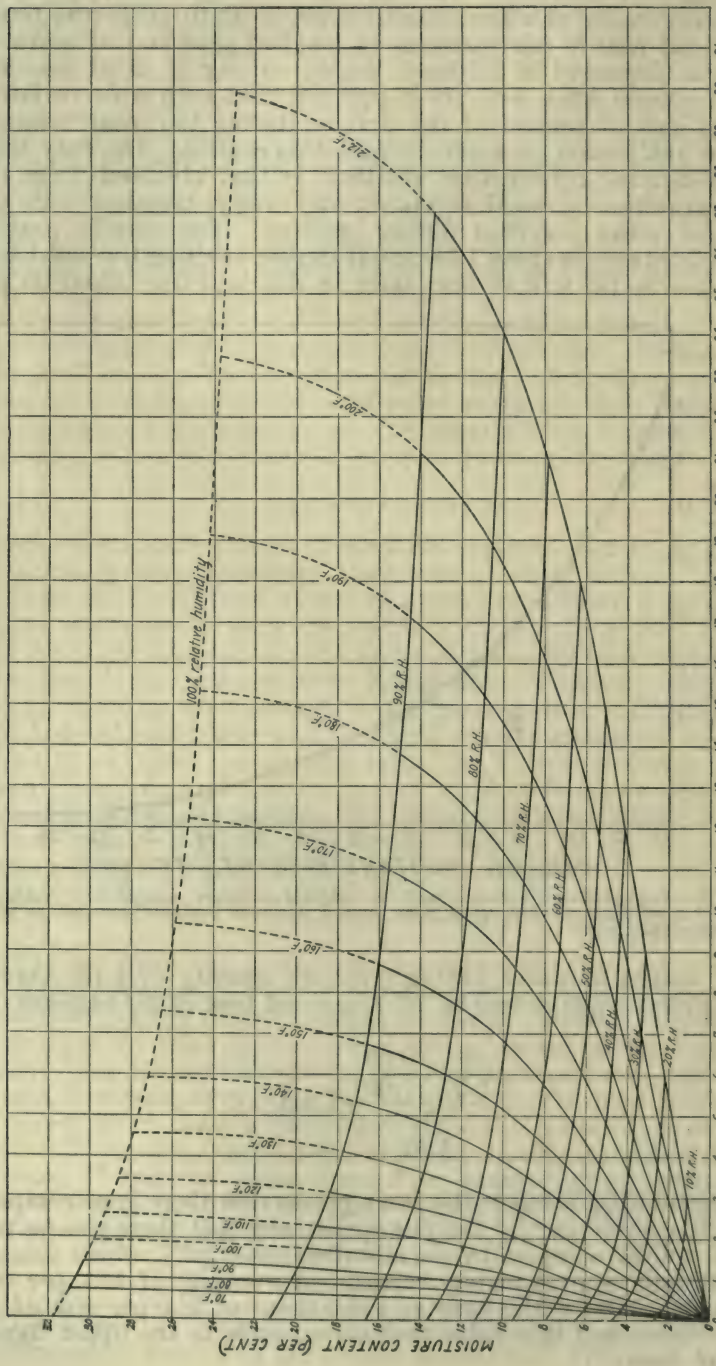

FIGURE 4.—The moisture-content values of Sitka spruce at equilibrium with various temperatures, partial vapor pressures, and relative humidities

Although a large amount of data on the swelling and shrinking of blocks and boards has been published, such information is not suitable for fundamental consideration on account of the effect of the wood structure on the transmission of the swelling of the wood substance to the external dimensions of the block. Roth has shown one instance in which only one-third of the shrinkage of the cell wall was effective in changing the outside dimensions of a microsection. There is a wide variation in the shrinkage of the outside dimensions of blocks, not only in different species but also in different directions in the wood. And, further, difference in the conditions of drying, which affect the degree of surface set in casehardened pieces, likewise causes variation in such shrinkage. For instance, in measurements made on a large number of species grown in the United States (*10*, *12*) the volumetric shrinkage from a saturated to an oven-dry condition varied from 7.3 to 25 per cent, the linear tangential shrinkage from 3.6 to 15.3 per cent, and the radial from 2.1 to 8.2 per cent. The longitudinal shrinkage of normal wood is only a few tenths of 1 per cent (*5*). It is probable that these variations in outside shrinkage are due entirely to variation in the wood structure and not to any variation in the amount of shrinkage of the wood substance.

Differential swelling measurements (*3*, *29*, *13*) have been made only on pieces of considerable size so that they do not give accurate quantitative relationships between absorbed water and swelling, although they do show the general relationship. This relationship appears to be linear over the whole range of water absorption except, perhaps, in the immediate vicinity of the fiber-saturation point, where the data are less reliable anyway.

EFFECT OF ABSORPTION ON VAPOR PRESSURE

The effect of absorption on the vapor pressure of the water absorbed is shown in the curves of Figure 4. The shape of these curves corresponds to that of Figure 3 in that the greater diminution of vapor pressure is accompanied by the greater heat of absorption. The data expressed in these two sets of curves were obtained from two species of wood only, pine and Sitka spruce, and other species might show some slight variations. The general shape of the curves, however, would be the same for all species.

The solid lines in the curves[7] of Figure 4 are based on experimental data; the dotted parts of the lines are calculated.

EFFECT OF MOISTURE CONTENT ON STRENGTH

The effect of absorbed moisture on the strength of wood has been determined for a considerable number of species. The general form of the curves for all the species tested is shown in Figure 5, which records the results of different strength tests of Sitka spruce. The point at which there is no further change in strength with change in moisture content seems to vary somewhat with the species and perhaps with the type of test. At present there is no explanation for this apparent variation.

[7] The data represented in these curves are the work of W. K. Loughborough.

EFFECT OF MOISTURE CONTENT ON ELECTRICAL PROPERTIES

Stamm (*20*, *23*) has recently studied the quantitative relationship between the moisture content and the electrical conductivity of wood

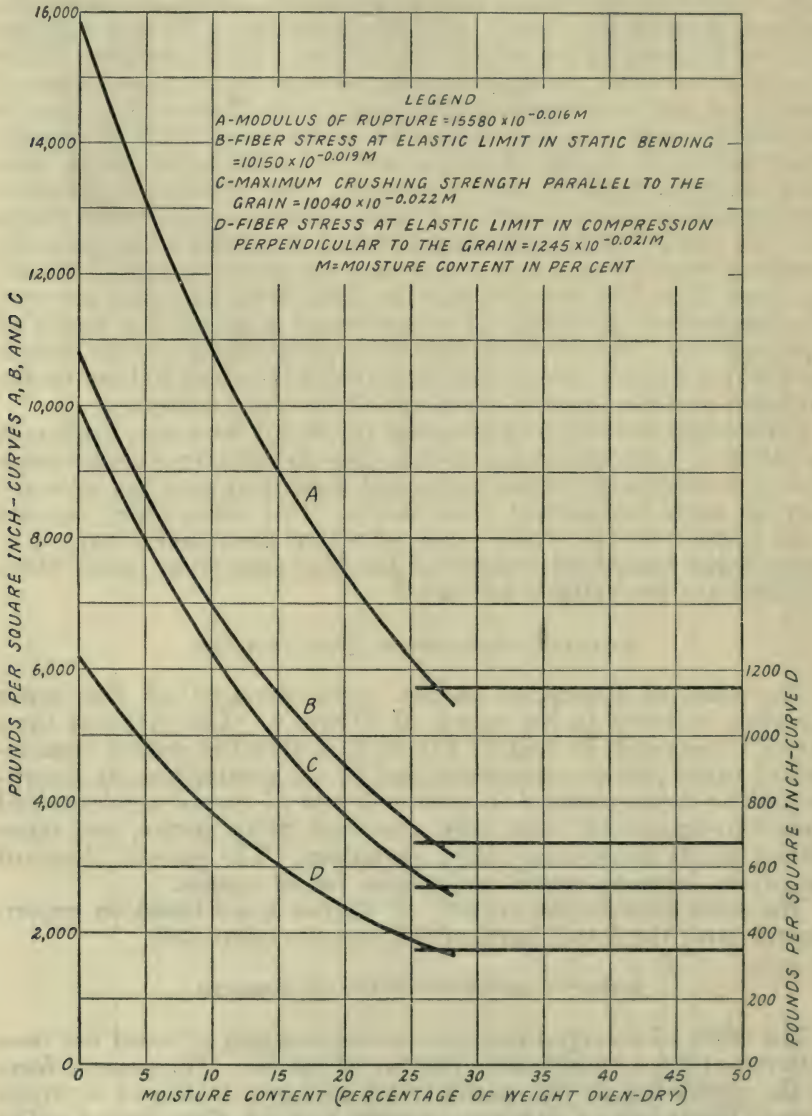

FIGURE 5.—The relation between the strength and the moisture content of small, clear specimens of Sitka spruce

substance. He found that the logarithm of the conductivity varied directly as the percentage of absorbed water, up to the fiber-saturation point; Figure 6 gives a typical curve showing this relationship. As with previously mentioned properties, the absorbed water

has a quantitative effect different from that of the free water; the curve indicates this fact. Table 1 shows that electrical resistance, like many other properties, is different in the different directions in wood.

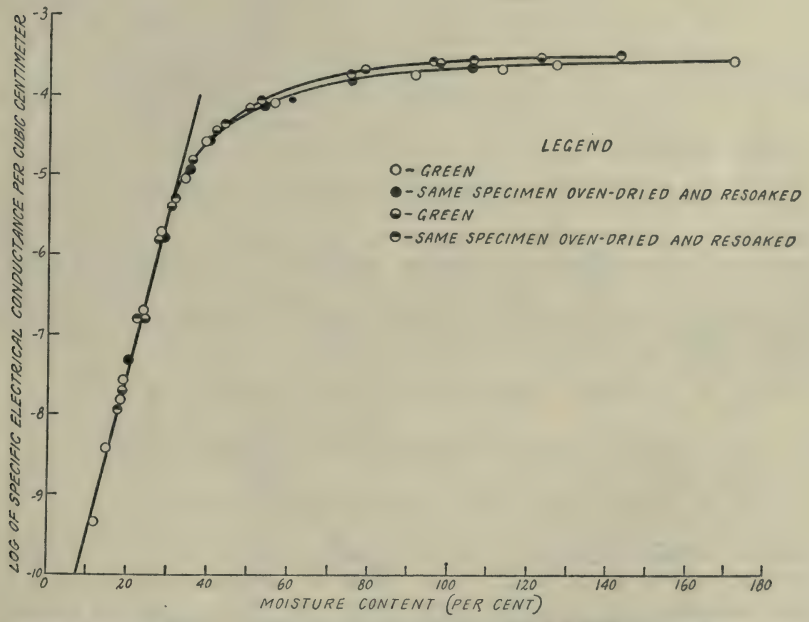

FIGURE 6.—The effect of moisture content on the specific electrical conductance of nonextracted redwood

TABLE 1.—*Typical variation in the electrical resistance of wood in its different structural directions*

Species	Moisture content	Electrical resistance		
		Longitudinal	Radial	Tangential
	Per cent	*Megohms*	*Megohms*	*Megohms*
Western red cedar	14.0	9	22	24
Sitka spruce	15.7	10	18	20
Alaska cedar	15.6	18	27	27
Douglas fir	15.3	11	21	23

The condensive capacity of wood under different moisture-content values would not be expected to show a change in value at the fiber-saturation point but should remain directly proportional to the relative amounts of wood and of water and to their dielectric constants (specific inductive capacities). There are no experimental data available to substantiate this statement as far as wood is concerned. The few data that are available are given in Table 2 (*19*); they are merely the dielectric constants for woods of unknown moisture content.

TABLE 2.—*Dielectric constants (specific inductive capacities) of wood of unknown moisture content*

Species	Dielectric constant	
	Parallel to grain	Perpendicular to grain
Red beech [1]	2.51–4.83	3.63–7.73
Oak	2.46–4.22	3.64–6.84

[1] Possibly a European wood.

EFFECT OF MOISTURE CONTENT ON THERMAL CONDUCTIVITY

Figure 7 gives a typical example of the findings of Griffiths and Kaye (*2*) on the effect of moisture content on the thermal conductivity of wood. The range in moisture content that their experiments embraced was too small to show whether the effect of absorbed water is different from that of free water.

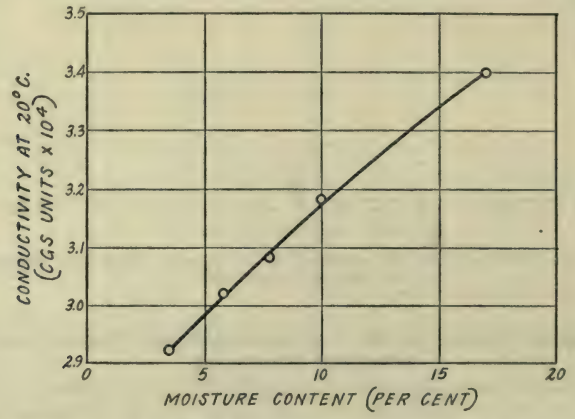

FIGURE 7.—The effect of moisture content on the thermal conductivity of spruce

In addition to the effects of moisture the same investigators found that, over the range in moisture content shown in Figure 7, the longitudinal thermal conductivity is about twice that of either of the transverse conductivities, while the radial conductivity is usually 5 or 10 per cent greater than the tangential.

THE FIBER-SATURATION POINT

The term "fiber-saturation point" was first used, by Tiemann (*26*), to designate the moisture content at which further reduction causes an increase in the strength of the wood. As other water-absorption phenomena were studied the term gradually came into use to express the more general conception of the limit of absorption of water by wood substance, and it will be used in that meaning in this bulletin. Although the fiber-saturation point has been determined by several methods, no complete and accurate study of differ-

ent species and specimens has been carried out. Figures 4, 5, and 6 indicate methods by which the fiber-saturation point may be determined; none of them, however, are entirely satisfactory.

The points where the temperature curves of Figure 4 intersect the 100 per cent relative-humidity curve indicate the fiber-saturation points at the respective temperatures. Most of these points were not actually determined—as indicated by the dotted portions, most of the temperature curves were extrapolated (by calculation) above the 90 per cent relative humidity intersections. The fiber-saturation point can not be accurately and directly determined by the method of Figure 4 because of the small capillaries (the cell cavities) existing in the wood. In a saturated atmosphere these cavities will condense moisture and consequently will give an apparent fiber-saturation point much higher than the actual value that is due to the water absorbed by the cell wall. It is possible that with thin transverse sections of wood or with relative humidities of say 99.8 per cent this difficulty could be avoided and close approximations made to the true limit of absorption. Volbehr (*31*) has reported a determination of the fiber-saturation point of pine wood made by this general method, with a result of 29.03 per cent, but he does not describe the details of his technic.

The relation between moisture content and strength shown in Figure 5 offers a method for determining the fiber-saturation point, but it is not a simple one because of the large number of observations and tests required to give accurate average results. In several series of strength tests similar to those of Figure 5, the fiber-saturation points of a number of woods have been found to vary between 20 and 31 per cent in average values, with an even greater range between individual values (*26*, *27*). This wide variation in the results obtained in the past indicates a lack of suitability in this method for determining the fiber-saturation point; the curves of Figure 5, however, may show that increased refinement in test and work-up will give more nearly consistent results. On the other hand, there is some evidence that even within the same species the indicated fiber-saturation point may vary with the particular strength value investigated.

Figure 6 shows some results obtained by a rapid and fairly accurate method for determining the fiber-saturation point. Thin sections of wood were used so that the desired moisture content could be readily obtained without a moisture gradient. The break in the curve that presents the relation between moisture content and electrical conductivity is not sharp enough to give an accurate determination of the fiber-saturation point, but the results plotted in Figure 6 show that the break comes at 30 per cent $\pm$ 1 per cent.

The relation between swelling and moisture content has also been used for determining the fiber-saturation point. Theoretically there should be no shrinkage of green wood on drying until the fiber-saturation point is reached, but here also the effects of the wood structure and of unequal moisture distribution prevent accurate determinations by this method (*13*).

It is evident that many more careful and precise determinations are needed to give conclusive and detailed information on the fiber-saturation point of wood; they should cover such matters as the

variation in different species, the variation at different temperatures, and the variation after different treatments. The few existing determinations show too much divergence to be satisfactory.

REVERSIBILITY OF ABSORPTION

Very little is known about the reversibility of the absorption of water by wood. Although this absorption seems to be substantially completely reversible there are indications that drying wood to a very low moisture content or subjecting it to elevated temperatures (*6*) permanently changes the value of the equilibrum moisture content. Further, like pure cellulosic fibers, wood has a hysteresis effect, with a difference in the equilibrium values when absorbing and when giving off moisture (*1*, *14*, *30*).

ABSORPTION OF LIQUIDS OTHER THAN WATER

Even less is known about the absorption of liquids other than water, although there are a few scattered data on the subject. The relative swelling effects of different liquids on dry birch wood have been determined by Hasselblatt (*3*) as shown in Table 3. The liquids are arranged in the table in the order of decreasing polarity, and the amount of swelling is seen to decrease in the same order. By an indirect method Stamm found in the absorption of liquids of various polarities consistent differences that are similar to the differences indicated in Table 3 (*22*). Dunlap has reported that turpentine and coal tar creosote give heats of absorption of 2.3 and 5 calories per gram of wood, in comparison with the 14.6 to 19.6 calories for the heat of absorption of water. Wieben [8] found that white spruce absorbed about 4.5 per cent by weight of kerosene from air saturated with kerosene vapor and 5 per cent of xylol under a similar condition. Theses figures may not be the maximum amount because the tests were not run to equilibrium, but they are probably somewhere near the equilibrium value.

TABLE 3.—*Tangential swelling of birch (dried at 110° C.) in various liquids*

Liquid	Percentage increase over original dimension	Liquid	Percentage increase over original dimension
Water	13.6	Turpentine	1.8
Glycerin	13.1	Benzol	.7
Ethyl alcohol	9.4	Carbon bisulphide	.8
Propyl alcohol	9.5	Decaline	.3
Acetone	9.1	Petroleum	.3
Ethyl ether	4.4	Ligroin	0
Chloroform	4.2		

There are no quantitative date available on the subject of the effect of the absorption of liquids other than water on the physical properties of wood. Tiemann has shown, however, that air-dry wood (about 12 to 15 per cent moisture content) soaked in turpen-

[8] WIEBEN, A. M. STUDY OF THE RELATIVE ADSORPTION OF WOOD FOR WATER AND VARIOUS OILS. 33 p., illus. 1922. [Unpublished thesis, Univ. Wis.]

tine, kerosene, or coal tar creosote gives decreased strength values, although the values are not decreased to the same extent that they are when the wood is soaked in water (*26*).

DYNAMICS

This bulletin has already discussed the structure of wood and the static relations between liquids and the cell-wall substance of wood. In brief résumé, wood in general is made up largely of longitudinally arranged hollow elements from 0.5 to 8 mm. in length, from 0.003 to 0.4 mm. in inside diameter, and from 0.002 to 0.04 mm. in thickness of wall between two adjoining cavities. These elements, either tracheids, fibers, or vessels, communicate with one another by means of extremely small but numerous openings through thin membranes; the openings, which are of unknown shape, have the effective size of circular apertures 11 mμ to 184 mμ in diameter for softwoods, and probably are substantially the same for hardwoods. In addition there is another and much smaller system of radially arranged cells, shorter than the fibers, which communicate with one another and with the adjoining longitudinal fibers through apertures of unknown shape and size that probably are similar to those between the fibers. The walls of which this structure of intercommunicating passages is built up are composed of a reversible aqueous jelly that can absorb, with swelling, about 29 per cent of its weight of water and less amounts of other liquids. With the preceding information concerning this structure and the properties of the substance composing it as a part of the basis, the conditions under which liquids may exist in wood and move through wood may now be discussed.

Liquids may exist in wood in three forms: (1) As free liquid in the cell cavities, (2) as bound liquid in the cell walls, and (3) as vapor in the cell cavities. Since the vapors in wood under practical conditions are always mixed with some gas, that is the only condition of vapor existence which will here be discussed. The free liquid can exist only when the adjacent wood substance is at the fiber-saturation point, but the other two forms occur at all values of moisture content (except that the vapor form will be absent in cells completely filled with liquid). Movement of free liquid can therefore take place only above the fiber-saturation point, and bound liquid and vapor can diffuse in response to variation in concentration or in vapor pressure only below the fiber-saturation point. All three movements can take place simultaneously, however, in different parts of the same small piece of wood. Certain general physical laws govern fluid movements of these types and with their aid it may be possible to correlate the known structure and properties of wood with the existing experimental data and thus obtain some evidence on the probable mechanism of the movement of liquids through wood, especially under the conditions that prevail in the practical processes of impregnation and drying.

IMPREGNATION BY PRESSURE

The impregnation of wood by liquids under pressure, as in the preservation process, is probably the simplest case of the movement

of a liquid in wood, because it consists almost entirely of the movement of free liquid. If the impregnating liquid is an oil that is only slightly absorbed by the cell wall, the bound-liquid movement will be negligible. If on the contrary it is a water solution, since the cell walls are already partly saturated the only bound-water movement will then be merely that required to complete the saturation by absorption from the free water as it comes in contact with the partly saturated cell wall. In either instance the vapor movement will be negligible in comparison with the amount of free-liquid movement. It is permissible, therefore, to consider impregnation as the movement of free liquid only. If it is such, the movement should follow the well-known laws governing the flow of liquids through small tubes. A simplified expression of these laws is given by Poiseuille's equation,

$$\frac{V}{t}=\frac{\pi r^4 P}{8\eta l} \qquad (1)$$

in which V represents the volume of liquid that has flowed, t the time of flow, r the radius of the tube, P the pressure, η the viscosity of the liquid, and l the length of the tube, all in centimeter-gram-second units. The equation is not directly applicable to the impregnation of wood by liquids because it expresses the conditions of liquid flow through tubes already filled with liquid, while the commercial impregnation of wood both involves the flow of liquid into empty tubes and includes a variation in the value of l. The mathematical relationship between these two types of flow will be developed later in this report. Before this is done, however, it will be necessary to discuss other variables, not used in equation (1), that may affect the flow of liquids through or into wood.

LOCALIZATION OF RESISTANCE TO FLOW; IMPACT TURBULENCE

As already indicated, the open passages through wood are not capillary tubes of constant diameter as required by Poiseuille's equation but are instead a series of discontinuous capillary tubes (the cell cavities) communicating through numerous orifices very much smaller than the tubes themselves. The orifices are so small, comparatively, that practically all the resistance to the flow of liquids is localized in them, and hence the resistance to flow in the cell cavities may be considered negligible (*21*). The sudden change in diameter of the passages, from an orifice to a cell cavity, brings in another variable, impact turbulence, not included in Poiseuille's equation. The effect of impact turbulence can be computed from Couette's modification (*22*) of Poiseuille's equation. Under the average conditions prevailing in the impregnation of heartwood, impact turbulence is negligible. Even under the most exceptional conditions that might occur locally or temporarily in the flow of the impregnating liquid through the cell cavities of heartwood the maximum correction to be applied to computations from equation (1) would be only about 1.6 per cent. Therefore the effect of impact turbulence need not be considered in the further discussions of impregnation.

EFFECTS OF CAPILLARY FORCES

When liquid is entering either an empty capillary or a gas-filled one the flow is affected by the surface tension of the liquid at its entering surface, which for the gas-filled capillary is the boundary between liquid and gas. The effect of the surface tension may be expressed quantitatively in terms of pressure tending to cause flow, and the general phenomenon of surface tension modified by size of capillary is often called "capillary pressure." Since this pressure may be exerted either toward or away from the surface, depending on the shape of the surface film, it may be either a positive or a negative pressure in so far as the internal pressure of the liquid is concerned. It is often expressed, however, as a positive pressure acting in one direction or the other. The discussion immediately following and also the discussion of Figures 11 to 14 make it desirable to restate here the preceding well-known facts.

Under the conditions postulated for the Poiseuille equation no capillary forces are acting. Such forces, however, not only may act but may also become important when the liquid is entering capillary spaces in wood that are filled with air. If the liquid wets the wood the capillary forces tend to pull the liquid into the empty spaces; that is, the resultant of these various forces acts in the same direction as the pressure applied to the liquid from the outside of the piece. The capillary pressure varies inversely as the radius of curvature of the meniscus, which in turn depends upon the radius of the capillary, and the cell cavities are small enough to give, with water as the liquid, about half an atmosphere of capillary pressure—a value not large in comparison with the external pressures applied in practice. The capillary pressures caused by meniscuses in the orifices in the pit membranes, on the other hand, may be greater than 50 atmospheres, although they are practically ineffective in assisting to force liquid into the wood on account of the extreme thinness of the membranes and the correspondingly short distances through which the high values are active. In fact the pit membranes may actually retard the capillary rise of liquid into wood on account of the large angle of the surface film just after the orifices have become filled with liquid.

If the liquid does not wet the wood, the resultant of the capillary forces acts in the direction opposite to the direction for water, that is, against the flow of the liquid into the empty spaces. In this case, however, it is the small, short capillaries of the pit membranes that are most important, since they determine the minimum force required to cause the initial flow of liquid into a cavity. With a liquid that does not wet wood a pressure as high as 50 atmospheres may be required to overcome the capillary pressure and cause a flow from one cell cavity to another.

As long as the liquid wets the wood, therefore, the effect of variation in surface tension is not important in modifying the externally applied pressure, but whatever its surface tension a liquid that does not wet the wood can be forced through the small orifices only by extremely high pressures. Although the liquids used for treating wood do wet the wood under normal conditions, yet there may be

temporary and localized resistance to wetting caused by extremely small surface deposits of materials not wet by the liquid. A strictly analogous occurrence is often noted in the flow of water into glass capillaries that are not perfectly clean. If such resistances to wetting were localized in the small orifices they would be important in preventing, or at least in retarding, the flow of the liquid.

TRAPPED AIR

During the impregnation of wood the air in the cavities may be trapped in two different ways, which have different effects on the impregnation process. In the more apparent way the air occupies the central, untreated portion of the piece, and in the more important one it forms bubbles in the cell cavities that are otherwise filled with the treating liquid. The first of these bodies of trapped air is not likely to be of appreciable moment in its effect on impregnation. Even if no air were trapped as bubbles and all the air formerly in the treated portion of the piece were displaced toward the center, its pressure would thereby be raised only in the ratio of the volume of the air displaced to that of the air previously in the untreated portion. For example, if one-half the piece is treated and all the air is therefore compressed into one-half the volume it originally occupied, the pressure of the compressed air is only doubled, and if it were at atmospheric pressure at the start it would then be at a pressure of only two atmospheres. An increase in internal pressure of an atmosphere or so is small in comparison with the external pressures of 7 to 15 atmospheres commonly applied in practice. Furthermore, the amount of air trapped as bubbles correspondingly decreases this effect. Usually the treating liquid penetrates less than one-half the piece, as one more consideration, and in the experimental data to be considered later in this bulletin less than one-half was thus penetrated.

The effect of air trapped as bubbles in the liquid is much more complicated. That this kind of air entrapment does take place, however, is easily established. It is proven by the "kick back" of the liquid, the reversed flow of liquid out of the wood that occurs when the pressure is released after the impregnation treatment has been finished. Although it may be thought that the kick back is caused by the air that has been compressed in the untreated, central portion of the piece, this can not be the fact because the air compressed in the center of the piece can not expand further than to the nearest small orifices. When the liquid has retreated until the dividing surfaces between the air and the liquid lie within these orifices, the capillary pressure resisting further retreat may be as high as 50 atmospheres, a pressure far greater than that of the compressed air. The kick back at ordinary commercial treating pressures must be due, therefore, to the combined effect of the expansion of many small air bubbles trapped in the liquid.

The kick back caused by the expansion of trapped air is occasionally accompanied by a similar effect caused by the expansion of the wood itself upon the release of the applied pressure. This effect is noticeable chiefly in species of relatively low mechanical strength that are resistant to impregnation treatment and when

high temperatures and pressures are used. Since only the total kick back can be measured, it is difficult to estimate the individual amounts that are due, respectively, to each of the two possible causes.

The air confined in the central, untreated portion of the piece affects the impregnation directly in that its pressure is substracted from the applied pressure to give the total effective pressure. The effects of the air trapped as bubbles are much more involved and are correspondingly difficult to estimate, especially the immediate effects as distinguished from the later kick back. If there were no change in the pressure to which these bubbles are subjected they would have no effect on the amount of flow. Since, however, the bubbles are subjected to increasing pressures and therefore diminish in size as the impregnation proceeds, the cell cavities in which air is trapped are not filled to their final capacity when the liquid enters them initially but continue to fill with liquid throughout the course of the impregnation process. The quantitative aspects of this effect will be discussed later in this bulletin.

FLOW OF IMPREGNATING LIQUID

Before discussing the effect of such variables as viscosity and pressure on the amount of liquid injected into wood in the impregnation process, it is desirable to develop the mathematical relationship between the type of flow covered by equation (1) and that which takes place during treatment. This can readily be accomplished after making the simplifying assumptions that the structural conditions of the wood remain substantially unchanged during impregnation and that the dimensions of the different cell cavities and the number and dimensions of the communicating passages between the different cell cavities are the same throughout the wood. Although the last assumptions are obviously untenable, the flow through a large number of cavities and communicating passages, even though the channels have widely varying dimensions, would be much the same as that through equivalent channels having constant dimensions, and the assumptions are therefore justified for their present purpose.

The results of experiments in wood impregnation are naturally expressed in terms of total amount of liquid absorbed or in depth of penetration. Such terms evidently bear a relationship to the V, volume, in equation (1), but the exact nature of the relationship must be ascertained. Washburn (*32*) has already developed such a relationship for capillaries of uniform bore, but his equation does not apply under the conditions under discussion because, as already pointed out, the flow of liquid into wood may be safely considered as the filling of successive reservoirs (the cell cavities) through extremely restricted and short communicating orifices (the pores in the pit membranes), the resistance to flow as expressed by r and η being located practically entirely in the orifices. The flow of the liquid during impregnation can therefore be considered as a series of discontinuous flows, the conditions remaining constant while one set of cell cavities is being filled and the resistance increasing stepwise by a practically constant amount as each set of cell cavities is filled and the liquid begins to flow through the next set of orifices.

Accordingly, if it takes one unit of time to fill the first set of cavities through one set of orifices, it will take two units of time to fill the second set of cavities, since for the second filling the liquid must flow through two similar sets of orifices in series; the third set of cavities will require three units of time, and so on. If, then, y is the depth of penetration, b the dimension of a cell cavity in the direction of the flow, x the time required to penetrate the depth y, and a the time required to fill the first cell, when $y/b=1$, $x/a=1$; when $y/b=2$, $x/a=3$; when $y/b=3$, $x/a=6$; and so on. The relation between y/b and x/a is therefore given by the equation

$$\frac{x}{a}=\frac{y}{b}\left(\frac{\frac{y}{b}+1}{2}\right),$$

or

$$x=ay\left(\frac{y+b}{2b^2}\right) \tag{2}$$

Equation (2) requires that every row of cells be either completely filled or at least filled to the same extent, and that the final maximum filling of each row take place before the next row begins to fill. Air bubbles trapped in the cell cavities prevent the individual fulfillment of both of these requirements, (1) because, although each cell may be originally filled to the same extent (to the stage where the entrapment of air is finished), the final subsequent compression of the trapped air and the corresponding additional amount of entering liquid that remains in the cell will vary according to the pressure on the liquid finally attained, and (2) because as the trapped air is compressed the cell continues to fill with liquid after the liquid has begun to flow into the cells beyond. Although the presence of trapped air thus destroys the actual quantitative relationship shown in equation (2) between the times required to fill the first row of cells and the subsequent rows, yet after the first two or three rows of cells have been filled the additional time required to fill each successive row becomes constant (to less than 1 part in 200) for any given piece, and this individually constant value is a function of the time required to fill the first row. This statement is introduced without proof because the development of the formulas and the computations on which it is based would take more space than the subject merits. If the statement is accepted, then equation (2) may be used exactly as it stands although a will then no longer represent the mathematically exact time required to fill the first cell but instead a function of that time, which has a practically constant value for a given case.

No attempt will be made to apply equation (2) to the experimental wood-impregnation data on the relation between time and penetration; it will be used only in applying equation (1) to the data on the effect of pressure and of viscosity.

MacLean's curves showing the relationship between time and penetration (7) are of the same general type as those given by equation (2) except for the considerable amount of absorption recorded as occurring at the very beginning of the impregnation, even before the maximum pressure has been attained. This rapid absorption at

the start is undoubtedly due to checks and ruptured cell walls that allow certain cavities to be filled without the passage of the liquid through apertures as small as those between the cell cavities. After this abnormally rapid first absorption, MacLean's curves can be closely duplicated by means of equation (2) with properly chosen values of a and b. The duplications are not exact, it is true, probably because the conditions assumed to be constant in the derivation of the equation were not actually constant during the experimental impregnations. The theoretical and experimental curves are so close, however, that the theoretical can be safely used in combination with equation (1) to deduce the effects of pressure and viscosity on penetration for comparison with the experimental results.

EFFECT OF PRESSURE ON PENETRATION

For all practical purposes y, the penetration, in equation (2) may be considered to vary inversely as the square root of a, the time required to fill the first cell. Although this relation between a and y, which is affected by the value of the constant b, is never strictly accurate, when y is large in comparison with b, as it always is except at the very beginning of the impregnation, the inaccuracy is negligible. According to equation (1) the time a required to fill the first cell should vary inversely with the pressure p. Therefore, other conditions remaining constant, the penetration y should vary as the square root of the pressure p. Yet MacLean's figures showing the effect of pressure on penetration do not give exactly such a relationship. The effect of pressure on penetration is not consistent in his different experiments; in general, however, the penetration he obtained varies more nearly directly with the pressure than with the square root of the pressure. The universal laws governing the flow of liquids in capillaries can not become suddenly inoperative in the impregnation of wood, and therefore some reasonable explanation of this apparent peculiarity must be sought.

If, as has been indicated in the previous discussion, the openings between the cell cavities are located in the very thin pit membranes, it seems reasonable to assume that pressure may cause a stretching of the membrane with consequent increase in the size of the openings. Hence all the conditions affecting the rate of flow, other than pressure, may not have been constant in the experiments. Rather, the size of the openings may also have varied, and may have varied as some function of the pressure. That this explanation is reasonable is further indicated by the fact that the same mechanism may be used in accounting for the observed effects of steaming the wood just prior to impregnation. Common practice in commercial plants is to steam the wood in order to increase the ease of penetration, and since steaming is known to soften the wood, making at least the macroscopic units of the wood substance more plastic, it probably increases the effect of pressure on the stretching of the membranes and therefore on the size of the openings.

EFFECT OF VISCOSITY ON PENETRATION

According to equation (2), the penetration should vary inversely as the square root of the time required to fill the first cell, and accord-

ing to equation (1) the time required to fill the first cell should vary directly as the viscosity. All other factors affecting impregnation being constant, the penetration should therefore vary inversely as the square root of the viscosity.

The experimental data showing the effect of viscosity on penetration are very meager. In most of MacLean's work (*7*, *8*, and *9*) on the effect of viscosity on penetration he obtained variation in viscosity by variation in temperature. The effect of viscosity alone, therefore, can not be determined from these data. In a few of his experiments, however, temperature was held constant and variation in viscosity was obtained by using mixtures of coal tar creosote with various proportions of petroleum oil. Four different petroleum oils were used, although only one at a time was mixed with the creosote. For the mixtures of creosote with any one oil, the relation between viscosity and penetration corresponds fairly well to the theoretical relation.

$$\text{penetration} = \frac{\text{constant}}{\sqrt{\text{viscosity}}},$$

although the constant is different for the different oils. Even when the results for all four oils are plotted together, there is a rough correspondence to a straight-line relationship between the penetration and the square root of the reciprocal of the viscosity. It may be concluded, therefore, that the experimental data, within the limits of their inconsistencies, confirm the deduction that the effect of viscosity on penetration in wood impregnation is what would be expected from the laws governing the flow of liquids in capillaries.

DIFFUSION CAUSED BY DIFFERENCES IN MOISTURE CONTENT

There are no data on the diffusion in wood of either pure vapor or pure bound liquid, and a detailed discussion of the diffusion equations that might apply is therefore unnecessary. It is of interest, however, to review the attempts that have been made to apply diffusion equations to experimental data obtained in the drying of wood. Tuttle (*28*) and later Sherwood (*18*) applied diffusion equations to the rate of drying of wood and found a good concordance of calculated and of observed results. In both instances, however, the wood was above the fiber-saturation point at the beginning of the experimental work, and the apparent success of the application of the diffusion equation proves only that the probably complicated mechanism actually in operation happened to have a resultant the same as that of the assumed simple mechanism; the success does not prove that the mechanism of the moisture movement corresponds to the assumptions of a simple diffusion. In fact the available information already reported herein demonstrates that this can not be so. The water existing in wood above the fiber-saturation point is free water, and free water has no properties that would cause it to diffuse from a point of higher to a point of lower concentration, as required by the diffusion law. Hence, in order to obtain details on the mechanism of moisture movement in wood through proper application of the diffusion laws it is necessary to use simplified cases in which the three different mechanisms that are possible in that movement may not all be in action at the same time.

The problem is simplified and the interpretation of results is less difficult when the experiments are conducted on wood below the fiber-saturation point so that instead of three there are only two possible ways of moisture movement—as vapor and as bound liquid. Stillwell (*24*) and Martley (*11*) have studied the diffusion of water through wood below the fiber-saturation point and have further simplified the interpretation by carrying on the diffusion at a constant rate, that is, with a constant high relative humidity on one side of a piece of wood and a constant low relative humidity on the other side. Under these conditions the distribution of the moisture, the moisture gradient in the direction of flow, may be expected to give some information on the mechanism of the diffusion. The usual diffusion equation assumes a driving force proportional to the differences in concentration of the diffusing substance. If this assumption held for wood, with no other variable affecting the rate of diffusion, and if the moisture diffusion through wood were entirely as bound liquid, the moisture gradient set up at the steady state should be a straight line as shown in Figure 8, A. If, on the other hand, the diffusion were entirely in vapor form, the gradient of vapor pressure should be a straight line at a steady state, but the graph representing the different moisture-content values of the wood in equilibrium with these uniformly varying vapor pressures would not be a straight line. Instead, the moisture gradients in equilibrium with a straight line of vapor pressures would have a form similar to the curve in Figure 8, B. The assumption that the driving force is proportional to differences in vapor pressure is undoubtedly true for pure vapor diffusion, but there is no evidence that the driving force is proportional to differences in moisture content in bound-water diffusion. On the contrary, the available evidence is opposed to such an assumption. It has been shown under the heading Statics (figs. 3 and 4) that the intensity of absorption of water by wood, as measured by heat of absorption and by diminution of vapor pressure, decreases greatly over the range from dry wood to the fiber-saturation point, and it might be expected that the diffusion constant would vary in the same

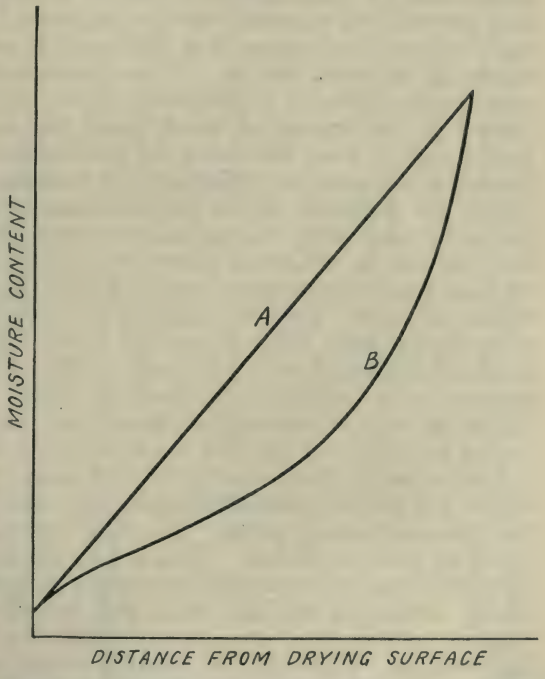

FIGURE 8.—Theoretical moisture gradients in wood at a steady state: A, When the moisture moves as bound water; B, when the moisture moves as vapor

manner. If this were so the moisture gradients caused by the diffusion of bound water should also resemble Figure 8, B.

Stillwell (*24*) found that the moisture gradients did not correspond closely to either of these assumptions but were more like Figure 8, A, or in some cases even convex from above. Nor did the rate of diffusion give any definite evidence of the mechanism. His work, however, was described as only preliminary in character, and certain experimental difficulties in the control of conditions were pointed out as affecting the results to such an extent that quantitative conclusions could not be drawn.

Martley (*11*), also making his experiments at the steady state, found that all his moisture gradients were curves convex from above and approached tangency to the horizontal at high values of moisture content, indicating that diffusion is more rapid at the higher values of moisture content. His experiments, therefore, do not indicate which diffusion mechanism, vapor or bound water, is preponderant in the drying of wood below the fiber-saturation point, but they do show that, whatever the mechanism, and whether difference in vapor pressure or difference in moisture content is the driving force, the diffusion is not proportional to the driving force alone. It varies also with the moisture concentration; this concentration may be that in the wood substance for the diffusion of bound water or that (partial pressure) in the air in the cell cavities for the diffusion of vapor. The same kind of a moisture gradient has been noted with drying soap (*18*), where the water is all bound water, and also in the diffusion of water through rubber (*17*), where the movement appears to be largely in the form of vapor. The fact that there is a variation with concentration, therefore, does not indicate any preference for either of the two possible forms of water movement.

Undoubtedly both forms of diffusion, as vapor and as bound water, are taking place at the same time in the drying of wood below the fiber-saturation point. The only question concerns the relative speed of the two forms. This can be determined by measuring the effect of some variable that can affect only one form of the diffusion or by adding a variable that can be affected by only one form. Studies of this kind are already under way at the Forest Products Laboratory. There is also another experimental method for differentiating between these two forms of moisture movement in drying; it is based on the fact that vapor diffusion requires heat for the evaporation of moisture in the interior of the wood, while bound-water diffusion requires heat for evaporation only at the surface. The temperature gradients in wood drying below the fiber-saturation point, therefore, may throw some light on this subject. Another suggested method is to study the rate of drying of wood saturated with a volatile liquid not absorbed or only very slightly absorbed by the cell wall, so as to exclude or at least minimize any diffusion as bound liquid.

MOVEMENT OF LIQUID ABOVE THE FIBER-SATURATION POINT

It has already been shown that the water occurring in wood above the fiber-saturation point is free water and that differences in moisture content above the fiber-saturation point, such for instance as between 40 and 50 per cent, do not in themselves develop any potential that can cause a flow from the higher to the lower concentration.

Yet there is evidence that free water moves in wood during the drying process. The main evidence, and all that needs to be considered here, is found in determinations of the moisture gradients at different stages of drying. If there were no movement of free water during drying the moisture gradients at successive periods would be as shown in Figure 9—curves A, B, and C, in order. All the movement of moisture toward the drying surface would then lie in portions of the piece below the fiber-saturation point, and the sharp break in the moisture content between the fiber-saturation point and the original moisture content would persist but would gradually move away from the drying surface. Such curves are in fact obtained with certain kinds of wood. On the other hand, certain other kinds of wood furnish moisture gradients similar to those of Figure 10, in which the original moisture content is seen to drop considerably before the fiber-saturation point is reached. The movement of free water is the simplest explanation of this type of moisture-distribution curve.

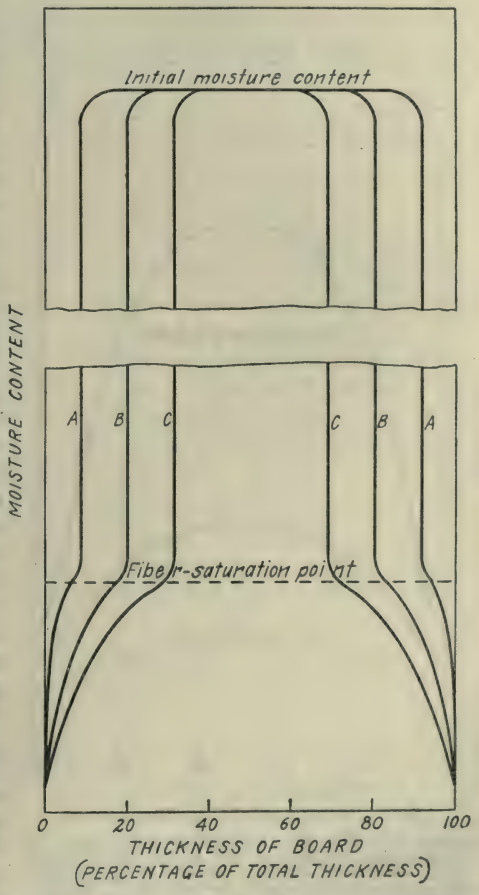

FIGURE 9.—The moisture-gradient in wood at three stages of drying when there is no movement of free water: A, at an early stage in drying; B and C, at successive later stages

Such a movement of free water during drying can be readily explained by the application of the information that has already been presented on the structure of wood and on wood-water relationships. Fortunately it is not necessary to assume that either vapor diffusion or bound-water diffusion is the more rapid in order to make this explanation. The movement toward the drying surface in that part of the piece of wood below the fiber-saturation point may be largely due to either of these mechanisms and yet the general effect on free-water movement will be the same. This explanation of free-water movement does in fact present a fairly complete and definite picture of the details of moisture movement during the drying of wood. It is not yet possible to give a quantitative treatment of the subject, but the following conception seems to fit the known facts and to furnish an acceptable presentation of the various mechanisms involved.

In addition to the foregoing it is only necessary to consider briefly the evaporation from the free surface of water in a capillary before developing the subject in connection with the drying of wood. As explained under the heading, Effect of Capillary Forces, capillary tension and pressure vary inversely with the radius of the capillary, and the same principle applies to a small bubble of air or other gas in a liquid. If, therefore, we consider a capillary of irregular cross section, Figure 11, filled with water except for a bubble, *b*, the system is in equilibrium only when the radius of the tube is the same at *a* and *c* and, if the gas in *b* is at atmospheric pressure, when the radius of *b* is also the same. If now evaporation of water takes place at *a* the retreat of the meniscus, *m*, toward a_1, with constantly decreasing radius of the tube, produces a constantly increasing capillary tension and, therefore, the meniscus *n* moves toward c_1, its radius always being equal to the radius at the other end of the tube. Meanwhile, with the capillary tensions at the ends of the tube increasing, the bubble *b* expands until the gas and vapor pressure within the bubble plus its capillary pressure are equal to the capillary forces at the ends of the tube plus the atmospheric pressure; the pressure within the bubble decreases as the bubble expands. With further evaporation at *m* this procedure will continue until the minimum radius is reached at a_1. Then, if a_1 is smaller than c_1 the meniscus *n* will continue to retreat toward a_1, and the evaporated surface will move forward and back between a_1 and the end of the tube, keeping *m* and *n* always of equal size until all the water in the tube is evaporated. If a_1 is larger than c_1, the meniscus *n* will not retreat beyond c_1, but instead *m* will continue to move toward *n*, until evaporation is complete. The presence of the bubble *b* does not materially affect the procedure under the conditions shown in the figure, but, if the minimum radiuses near the ends of the tube are

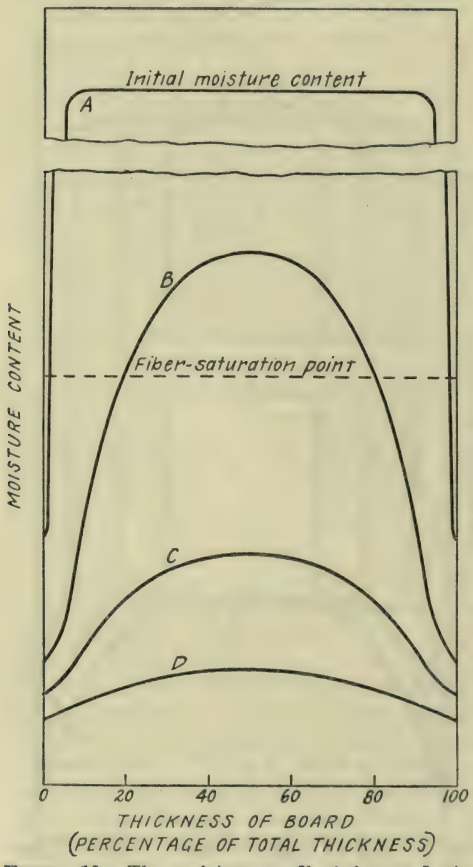

FIGURE 10.—The moisture gradient in wood at four stages in typical kiln-drying when there is a movement of free water: A, at a very early stage in drying; B, C, and D, at successive later stages

very small in comparison to the radius of b, sufficient capillary force may be developed to expand b very considerably. In fact, the minimum radiuses may be so small that the capillary forces will be greater than the tension of the liquid in the surface film of the bubble b, in which event m and n will both remain stationary while b expands until the tube is emptied of liquid water.

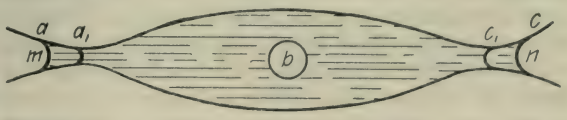

FIGURE 11.—A capillary tube of nonuniform bore, with a bubble of entrapped gas: a, One aperture; a_1, position of minimum radius of aperture a; b, a bubble of entrapped air or other gas; c, the other aperture; c_1, position of minimum radius of aperture c; m, meniscus at aperture a; n, meniscus at aperture c

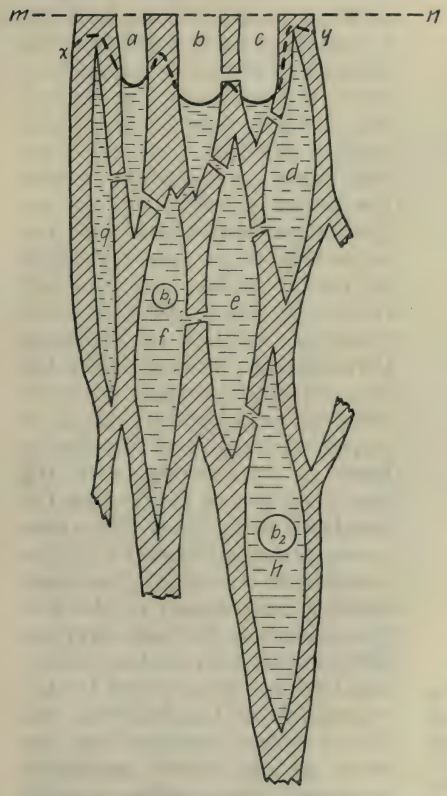

FIGURE 12.—An early stage in the drying of an idealized wood structure: a, b, c, d, e, f, g, and h, Fiber cavities in an idealized wood structure: b_1 and b_2, bubbles of entrapped air or other gas; mn, exterior surface of the piece of wood; xy, surface of the liquid in the cavities from which evaporation takes place

APPLICATION OF PRINCIPLES TO A SIMPLIFIED STRUCTURE

For the application of the preceding principles to the drying of wood we may use an idealized and simplified structure (figs. 12, 13, and 14) that resembles wood in all the details essential to this discussion. The cells selected for illustration have an inside diameter of about 0.01 mm. and the orifices connecting them have a diameter of about 70mμ. In Figure 12 all cell cavities when drying started were full of water, except f and h, which contained air bubbles. Evaporation from the surface of the wood mn lowers the water level in the cells a, b, and c, and at the same time the walls begin to dry out from the line mn downward. Further evaporation brings the water level down to the positions shown in Figure 12. Other evaporation of water is probably also taking place from the cell walls into the cell cavities, as indicated by the line xy, which marks the limit of fiber saturation in the cell walls. There is a definite capillary tension at each of the meniscuses in a, b, and c; these tensions, however, can have an effect in moving liquid water only when the curvature of any meniscus or bubble surface in the intercommunicating system is larger than the curva-

tures in *a*, *b*, and *c*. The level in *a* is shown as higher than the levels in *b* and *c* on account of the greater capillarity in *a* (*a* is slightly smaller than *b* and *c*). If the bubble in *h* has a diameter greater than the diameter of the meniscus in *a*, it will expand after evaporation from the surface at *a* until equilibrium is restored, in accordance with the action described in connection with the bubble in Figure 11.

Continued evaporation will finally bring about the situation indicated in Figure 13. Here the cells *a*, *b*, and *c* no longer contain water, and there is a meniscus across each of the orifices leading inward from these cells. On account of the great increase in the capillary forces in these small orifices over the forces previously exerted by the larger meniscuses in the cell cavities, the evaporating surface will tend to remain stationary within them as long as there are larger surfaces from which the water can flow to replace the evaporated water. At the same time there is evaporation of bound water into the cell cavities of *a*, *b*, and *c*; the bound water is supplied by diffusion through the cell walls from the free water in contact with the other sides. The bubbles b_1 in *f* and b_2 in *h* had previously been in equilibrium with the capillary forces exerted by the meniscus in *a*. Now they must come into equilibrium with the conditions set up by the much smaller meniscuses in the orifices between the cell cavities. The water evaporation along the line *xy* is supplied by the expansion of the bubbles, and the internal tension in the body of the water gradually increases, for a time, as this evaporation proceeds. The expansion of the bubbles during this stage is accomplished by expansion of the air contained in them and by evaporation into them of water from their surface films. Finally, however, the increasing vapor pressures of the water in the surface films become equivalent to the tension conditions in the body of the liquid, and then the bubbles continue to expand without further changes in liquid tension. This stage is reached by b_2 sooner than by b_1, since the size of the bubble and hence the vapor pressure in the surface film of b_2 is greater. The bubble b_2 expands until it fills the

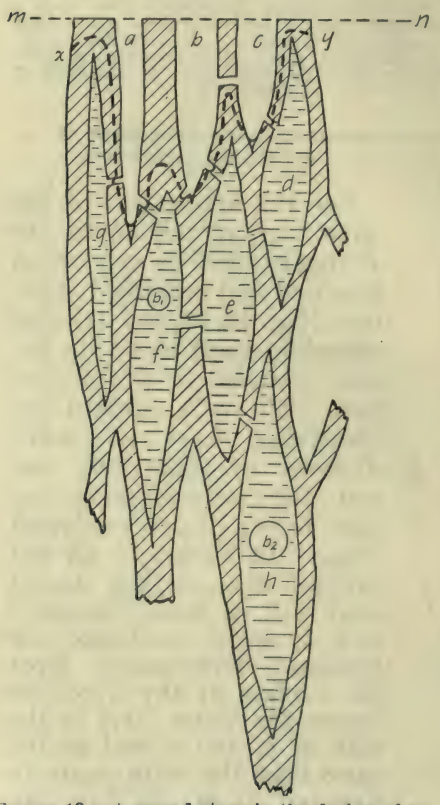

FIGURE 13.—A second stage in the drying of an idealized wood structure: *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h*, Fiber cavities in an idealized wood structure; b_1 and b_2, bubbles of entrapped air or other gas; *mn*, exterior surface of the piece of wood; *xy*, surface of the liquid in the cavities from which evaporation takes place

cavity *h*, all the water passing upward into *e*. This leaves a meniscus in the orifice between *e* and *h*, which will remain stationary as long as there are larger surfaces anywhere in the system to be moved first. The bubble b_1, being larger than any of the meniscuses now in the system, will expand under increasing tension until it reaches the second stage described for bubble b_2 and will then expand further at constant liquid tension until it fills *f*. Since there is now no water to sustain them the films in the orifices between *a* and *f*, and *f* and *b* will completely evaporate, and the pressure in *f* will be made normal by the entrance of air from *a* and *b*. The condition shown in Figure 14 is now reached. Only the three cell cavities *d*, *e*, and *h* are left active in the dead-end system, and the next development depends on the relative size of the orifices at which there are meniscuses. If the one between *h* and *e* is the largest (and is also sufficiently larger than the others to make up for the low pressure existing in *h*) it will be pulled into *e*, and the water in *e* will pass out partly through *d* and partly through the cell walls and orifices into *b* and *f*. If, however, the orifice between *c* and *d* is the largest of the group its meniscus will be pulled back into the cavity *d*, and on account of the low pressure existing in *h* a part of the water in *d* will flow through *e* to *h* until the pressure in *h* is again normal. Thus there is the interesting possibility of occasional flow of liquid water for a short distance in the direction away from the drying surface whenever a meniscus on the drying surface becomes greatly enlarged by being pulled back into a cell cavity.

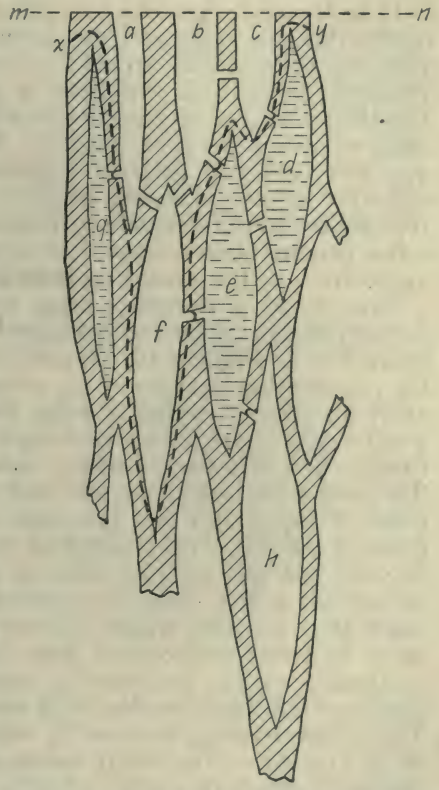

FIGURE 14.—A third stage in the drying of an idealized wood structure: *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h*, Fiber cavities in an idealized wood structure; *mn*, exterior surface of the piece of wood; *xy*, surface of the liquid in the cavities from which evaporation takes place

Collapse.—During the stages of Figures 12 and 13 the meniscuses between the cell cavities are not required to exert their maximum capillary tensions. Whenever a condition similar to that shown in Figure 14 exists, however, there will be a great mechanical stress in the walls of the dead-end system before one of the meniscuses is pulled through its orifice into a cell cavity. With orifices of an effective diameter of 70 mμ the tension required to pull a meniscus into the cell cavity would be about 40 atmospheres. So great a

force may be sufficient in some species of wood to cause a collapse of the cell wall; such collapse is frequently observed in dried wood. Although our knowledge of the submicroscopic structure and the initial moisture characteristics of the species most subject to collapse is still too meager for a definite substantiation of this explanation of the phenomenon, all that we do know is in agreement with it.

BRIEF APPLICATION OF PRINCIPLES TO ACTUAL WOOD STRUCTURE

It is thought that the foregoing greatly simplified presentation covers the principles and the essential details of the mechanism of free-water movement during the drying of wood. Numerous details pertinent even to so simplified a presentation are not included in the discussion, but all the details omitted seem of little importance in their effect on the gross results. No attempt will be made to give any complete and detailed application of these principles to the structure of actual wood, which is much more complex than that represented in the elementary diagrams of Figures 12, 13, and 14, but a few general observations will be made in amplification and partial application of the preceding restricted discussion.

Since wood is normally made up of continuously intercommunicating passages it has no completely closed systems like that shown below *mn* in Figures 12, 13, and 14. The capillary force set up at the evaporating surface of an actual piece of wood, therefore, may exert an effect through a large number of cell cavities. Even in a cell cavity nearly filled with an air bubble there are probably continuous fine columns of water (resulting from the irregularities in the interior surface of the cell wall) that persist even at considerably reduced vapor and gas pressures and thus allow a flow of water through the cell. On account of the very small size of the openings between the cell cavities there is a considerable resistance even to so reduced a flow, and the openings may in certain instances be so small that the free water can not flow to the free surface as fast as it is being evaporated from the surface. In such event the meniscuses on the evaporating surface may be broken by evaporation, and the liquid surface will then recede to the next row of cells. This illustrates the manner in which a moderate variation in size or in number of the small openings between cell cavities may considerably affect the mode of drying, as indicated by the moisture gradients. Qualitatively the mode of drying is always the same—there is always some movement of free water in response to the capillary force developed at the drying surface, but this movement may extend only a few tracheids beyond the evaporating surface before the evaporating surface begins to progress inward. The result is a moisture gradient similar to those shown in Figure 9, because the distance through which free water moves in such drying is so small as to have very little effect on the gradients. Since the flow varies as the fourth power of the radius a moderate increase in the average size of the openings will cause a considerable decrease in the resistance to flow, and the movement of free water may then extend for many tracheids beyond the evaporating surface, giving gradients similar to those in Figure 10.

The picture so far presented is substantially one of movement in a longitudinal direction. The movement in a tangential direction

differs from the longitudinal only in the relative rates at which movement takes place. It should be slower because there are more membranes and hence more small openings in series per unit of distance from the drying surface than in the longitudinal direction. In the radial direction there are wood rays, which are oriented similarly to the cells in the longitudinal direction, in which the rate of movement should simulate the movement within the longitudinal cells, and consequently radial drying should partake of both longitudinal and tangential rates.

The preceding discussion of the movement of liquids in actual wood has also been limited largely to a restricted structure similar to that of a softwood without resin ducts. The presence of resin ducts or of the special vessel systems of hardwoods may greatly modify the details, but the principles and the general results will be the same.

There are no observations or experimental data on the evaporation from wood of liquids other than water so that this subject need not be discussed, but here again the general mechanism should be the same as with water.

CONCLUSIONS

Although this bulletin is essentially a review and correlation of known facts and principles it permits the drawing of definite conclusions.

Some specific conclusions are: In the impregnation of wood with liquids the effect of the viscosity of the liquid on the penetration is what would be expected from the known facts in regard to wood structure and the laws governing the flow of liquids into capillary tubes, whereas the effect of pressure on the penetration is not what would be expected, which indicates the existence of other variables not yet controlled, such for example as the effect of temperature on the plasticity of the wood. The movement of free water during the drying of wood depends on the size and the number of the openings between cavities containing water and on the proportions of air and water in these cavities.

Corollaries are: Experimental methods are suggested for determining the preponderance of vapor flow or of bound-liquid flow during drying below the fiber-saturation point. The lack of variety and of completeness in certain determinations, such as the fiber-saturation point, the size of openings in the wood structure, and structural details, especially the location and the number of pits, in different pieces and different species of wood, is pointed out.

Three conclusions are: (1) It is profitable, at an early stage in experimental work, to study the principles involved in the problem and, with the aid of all the known facts, to formulate a tentative hypothesis. (2) Mathematical formulas that fit experimental data do not necessarily give any information on what the fundamental variables are or on the relation between them; such formulas may even lead to a false conclusion in regard to the simplicity of the process. (3) In dealing with a material of complicated structure, like wood, it is necessary to know the finest details of the structure and to keep them constantly in mind in order to properly interpret experimental data or plan experimental work. These conclusions

may be considered trite and commonplace statements of prevailing opinion, but restatement and emphasis can do no harm in connection with a subject so important as efficiency in research methods.

SUMMARY

Many of the problems that occur in the drying and other preparation of green wood for use originate in the fundamental relations between wood and liquids. This bulletin summarizes the present knowledge of wood structure and of wood-liquid relations and thus serves as an introduction for a series of publications that will report experimental research on various parts of the general problem of establishing these relations. Further, the correlation of existing information has made possible the formulation of satisfactory hypotheses covering the detailed mechanism of the movement (1) of liquid water in wood during the drying process and (2) of the impregnating liquid during the preservative treatment of timber.

LITERATURE CITED

(1) CAMPBELL, W. B., and PIDGEON, L. M.
1930. HYDRATION OF CELLULOSE BY BEATING. Pulp and Paper Mag. Canada 29: 185–190, illus.

(2) GRIFFITHS, E., and KAYE, G. W. C.
1923. THE MEASUREMENT OF THERMAL CONDUCTIVITY. Roy. Soc. [London] Proc., Ser. A 104: 71–98, illus.

(3) HASSELBLATT, M.
1926. DER WASSERDAMPFDRUCK UND DIE ELEKTRISCHE LEITFÄHIGKEIT DES HOLZES IN ABHÄNGIGKEIT VON SEINEM WASSERGEHALT. Ztschr. Anorgan. u. Allg. Chem. 154: 375–385, illus.

(4) KATZ, J. R.
1917. DIE GESETZE DER QUELLUNG. EINE BIOCHEMISCHE UND KOLLOIDCHEMISCHE STUDIE. I. TEIL: DIE QUELLUNG IN WASSER OHNE KOMPLIKATIONEN. Kolloidchem. Beihefte 9: 1–182, illus.

(5) KOEHLER, A.
1924. THE PROPERTIES AND USES OF WOOD. 354 p., illus. New York.

(6) ——— and PILLOW, M. Y.
1925. EFFECT OF HIGH TEMPERATURES ON MODE OF FRACTURE OF A SOFTWOOD. South. Lumberman 121: 219–221, illus.

(7) MACLEAN, J. D.
1924. RELATION OF TEMPERATURE AND PRESSURE TO THE ABSORPTION AND PENETRATION OF ZINC CHLORIDE SOLUTION INTO WOOD. Amer. Wood-Preservers' Assoc. Proc. 1924: 44–73, illus.

(8) ———
1926. EFFECT OF TEMPERATURE AND VISCOSITY OF WOOD PRESERVATIVE OILS ON PENETRATION AND ABSORPTION. Amer. Wood-Preservers' Assoc. Proc. 1926: 147–167, illus.

(9) ———
1927. RELATION OF TREATING VARIABLES TO THE PENETRATION AND ABSORPTION OF PRESERVATIVES INTO WOOD. PART III: EFFECT OF TEMPERATURE AND PRESSURE ON THE PENETRATION AND ABSORPTION OF COAL TAR CREOSOTE INTO WOOD. Amer. Wood-Preservers' Assoc. Proc. 1927: 52–70, illus.

(10) MARKWARDT, L. J.
1930. COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U. S. Dept. Agr. Tech. Bul. 158, 39 p., illus.

(11) MARTLEY, J. F.
1926. MOISTURE MOVEMENT THROUGH WOOD: THE STEADY STATE. [Gt. Brit.] Dept. Sci. and Indus. Research, Tech. Paper no. 2, 22 p., illus.

(12) MATHEWSON, J. S.
1930. THE AIR SEASONING OF WOOD. U. S. Dept. Agr. Tech. Bul. 174, 56 p., illus.
(13) MEYER, J. E., and REES, L. W.
1926. ELECTRICAL RESISTANCE OF WOOD, WITH SPECIAL REFERENCE TO THE FIBER SATURATION POINT. N. Y. State Col. Forestry, Syracuse Univ., Tech. Bul. 19, 22 p., illus.
(14) PIDGEON, L. M., and MAASS, O.
1930. THE ADSORPTION OF WATER BY WOOD. Jour. Amer. Chem. Soc. 52: 1053–1069, illus.
(15) ROSENBOHM, E.
1914. UEBER DIE WÄRMEENTWICKELUNG BEI DER QUELLUNG VON KOLLOIDEN. Kolloidchem. Beihefte 6: [177]–200, illus.
(16) ROTH, F.
1894. UEBER DAS VERHALTEN DER VERHOLZTEN ZELLWAND WÄHREND DES SCHWINDENS. Bot. Ztg. 52: [217]–221, illus.
(17) SCHUMACHER, E. E., and FERGUSON, L.
1929. DIFFUSION OF WATER THROUGH RUBBER. Indus. and Engin. Chem. 21: 158–162, illus.
(18) SHERWOOD, T. K.
1929. THE DRYING OF SOLIDS—1. Indus. and Engin. Chem. 21: 12–16, illus.
(19) SMITHSONIAN INSTITUTION.
1929. SMITHSONIAN PHYSICAL TABLES. Prepared by F. E. Fowle, 4th reprint of rev. ed. 7, 458 p., Washington.
(20) STAMM, A. J.
1927. THE ELECTRICAL RESISTANCE OF WOOD AS A MEASURE OF ITS MOISTURE CONTENT. Indus. and Engin. Chem. 19: 1021–1025, illus.
(21) ———
1929. THE CAPILLARY STRUCTURE OF SOFTWOODS. Jour. Agr. Research 38: 23–67, illus.
(22) ———
1929. DENSITY OF WOOD SUBSTANCE, ADSORPTION BY WOOD, AND PERMEABILITY OF WOOD. Jour. Phys. Chem. 33: [398]–414, illus.
(23) ———
1929. THE FIBER-SATURATION POINT OF WOOD AS OBTAINED FROM ELECTRICAL CONDUCTIVITY MEASUREMENTS. Indus. and Engin. Chem., Anal. Ed. 1: 94–97, illus.
(24) STILLWELL, S. T. C.
1926. THE MOVEMENT OF MOISTURE WITH REFERENCE TO TIMBER SEASONING. [Gt. Brit.] Dept. Sci. and Indus. Research, Tech. Paper no. 1, 29 p., illus.
(25) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES: THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 259 p.
(26) TIEMANN, H. D.
1906. EFFECT OF MOISTURE UPON THE STRENGTH AND STIFFNESS OF WOOD. U. S. Dept. Agr., Forest Service Bul. 70, 144 p., illus.
(27) ———
1907. THE STRENGTH OF WOOD AS INFLUENCED BY MOISTURE. U. S. Dept. Agr., Forest Service Circ. 108, 42 p., illus.
(28) TUTTLE, F.
1925. A MATHEMATICAL THEORY OF THE DRYING OF WOOD. Jour. Franklin Inst. 200: 609–614, illus.
(29) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE, FOREST PRODUCTS LABORATORY.
1928. MANUAL FOR THE INSPECTION OF AIRCRAFT WOOD AND GLUE FOR THE UNITED STATES NAVY. 137 p., illus. Washington.
(30) URQUHART, A. R., and WILLIAMS, A. M.
1924. THE MOISTURE RELATIONS OF COTTON. II.—THE ABSORPTION AND DESORPTION OF WATER BY SODA-BOILED COTTON AT 25° C. Jour. Textile Inst. 15: T433–T442, illus.

(31) VOLBEHR, B. F. K. J.
1896. UNTERSUCHUNGEN ÜBER DIE QUELLUNG DER HOLZFASER. 37 p., illus. Kiel, Germany. (Inaug. Diss.)
(32) WASHBURN, E. W.
1921. AN INTRODUCTION TO THE PRINCIPLES OF PHYSICAL CHEMISTRY FROM THE STANDPOINT OF MODERN ATOMISTICS AND THERMODYNAMICS; A COURSE OF INSTRUCTION FOR STUDENTS INTENDING TO ENTER PHYSICS OR CHEMISTRY AS A PROFESSION. Ed. 2, rev., enl. and reset, 516 p., illus. New York.

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TECHNICAL BULLETIN No. 249 JULY, 1931

SOME FACTORS AFFECTING THE VISCOSITY OF CREAM

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page
Introduction	1
Method used for measuring viscosity	2
Method used for microscopic studies	2
Factors affecting viscosity	3
Effect of butterfat content and temperature	3
Effect of age upon viscosity	4
Effect of pasteurizing temperature	6
Gravity-separated and centrifugally separated cream compared	7
Effect of standardization	8
Effect of freezing	9
Factors affecting viscosity—Continued.	
Effect of acidity	9
Effect of cooling	10
Effect of separating temperature	11
Effect of storage of milk	12
Effect of pasteurizing before separating	12
Effect of homogenization	13
Effect of homogenizing temperature	14
Effect of rehomogenization	16
Effect of solids not fat	16
Conclusions	18
Literature cited	18

INTRODUCTION

Throughout the market-cream industry much difficulty is encountered by producers in preparing and marketing cream on account of variations in what is commonly referred to as "body". Consumers judge the quality of their cream supply mostly by its appearance; if the cream seems to be heavy or thick, its appearance is taken to indicate a high butterfat content, and vice versa. Therefore it is to the best interest of the dairies to supply a product which is uniform in appearance day after day. Dairies are attempting to do this and at the same time to supply a product with a good body. However, there is a tendency for the body of cream to vary even when the cream-handling processes are the same.

The experiments reported in this bulletin were made in order to determine, if possible, some of the causes for the variations in the body of cream, body being an important commercial factor. The body of cream, as determined by capillary flow, is reported throughout this work as viscosity. The fact that cream at the higher fat concentrations and lower temperatures gave indications of pseudoplasticity has not been considered.

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METHOD USED FOR MEASURING VISCOSITY

Viscosity may be defined as the internal friction of a liquid, the resistance to shear or flow. Usually it is measured by an instrument called a viscosimeter or viscometer, which permits a certain volume of liquid to discharge through a short capillary tube. The time of discharge is recorded in seconds. When the same instrument is used purely as a relative measure for the direct comparison of different liquids, the time of discharge in seconds makes an accurate comparison. If the make of instrument is stated and well known, the time in seconds may be used for the determination of viscosity with reference to a particular standard.

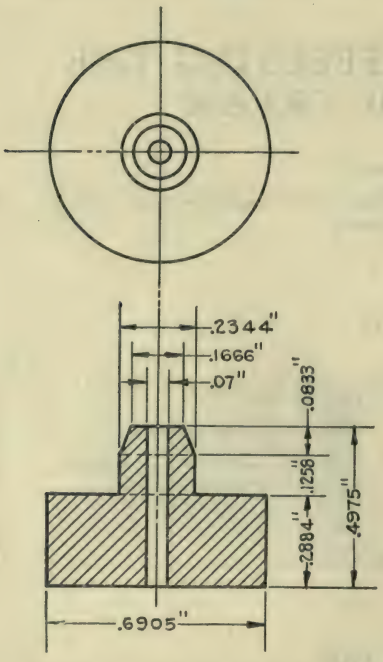


FIGURE 1.—Diagram showing orifice of the viscometer used in determining the viscosity of cream

In this work an instrument similar to the standard Saybolt viscometer was used, the main difference being that the orifice, which was 0.07 inch in diameter, was removable. (Fig. 1.) The viscometer held 70 cubic centimeters of liquid, and the time required for the discharge of the first 60 cubic centimeters was recorded in seconds. For the maintenance of constant temperatures, the viscometer was surrounded by a water bath. The temperature was determined by a thermometer passed through the lid of the viscometer into the center of the liquid within the viscometer. The results, which in nearly every case represent the average of at least 25 determinations, are recorded herein as relative viscosity, which may be defined as the relative internal friction of a liquid, and determined by taking that of water at the same temperature as equal to 1.

METHOD USED FOR MICROSCOPIC STUDIES

On account of the vast number of fat globules in cream it was necessary to dilute the cream before making a microscopic study. In this work the cream was diluted with a solution which was similar to that used by Van Dam and Sirks (*10*).[1] This solution consisted of 1½ parts of gelatin dissolved in 100 parts of water, to which phenol was added to make the solution 1 per cent phenol. This made a very satisfactory diluent, as the gelatin held the fat globules, thereby preventing the "Brownian movement." The phenol acted as a preservative agent, keeping the microscopic slides constant for a longer period and thus permitting a more accurate comparison

[1] Italic numbers in parenthesis refer to Literature Cited, p. 18.

of different slides. In this work the cream was diluted by using 1 part of cream to 100 parts of solution. In order that the amounts of cream on the slides would be comparable, a platinum loop was used to transfer a drop of the mixture to the slide. This drop was then covered with an ordinary cover glass.

FACTORS AFFECTING VISCOSITY

One of the main factors affecting the viscosity of cream is the physical state of the butterfat therein. The butterfat of fresh cream occurs mainly as individual globules, ranging in diameter from 0.1 to 22 microns. However, the greater number are below 10 microns, 3 microns being given by most investigators as the average size. The cream used in this investigation was, unless otherwise stated, centrifugally separated from the mixed milk of a herd consisting of Holstein, Jersey, and Guernsey cattle. The fat globules in 50 different samples of the cream averaged 3.19 microns.

There is a tendency for the fat globules to coalesce or to adhere to one another, forming aggregates or clumps. The degree of clumping depends largely upon temperature, size of globules, and agitation. Investigators agree that maximum clumping takes place at 7° to 8° C., and that above 60° little or no clumping occurs.

The larger fat globules apparently clump more readily than the smaller ones, for a microscopic examination of cream shows that the clumps contain but a very small proportion of the smaller fat globules. The fact that the fat remaining in skim milk is mostly in the form of globules less than 3 microns in diameter, indicates that the smaller globules have less tendency to coalesce.

As it is necessary for the globules to come into contact with one another before they can coalesce, agitation at temperatures favorable to coalescence increases the degree of clumping, whereas agitation at temperatures unfavorable to coalescence tends to disperse the globules or to separate the clumps previously formed.

Any factor which affects the clumping of fat globules affects the viscosity of cream. The clumping of globules begins in milk before separation. Centrifugal separation undoubtedly breaks up or disperses many of the clumps previously formed and at the same time forms many new clumps. Likewise, the various processes through which cream passes before reaching the consumer may alter the clumping of globules and thereby affect the viscosity of the cream.

EFFECT OF BUTTERFAT CONTENT AND TEMPERATURE

Whitaker, Sherman, and Sharp (*20*) report that the viscosity of skim milk decreases as the temperature is raised. Dahlberg and Hening (*8*) report that increasing the percentages of fat in milk and cream always increased the viscosity of the milk or cream, but the effect of increasing the amount of the fat was most marked when the cream contained 20 to 35 per cent fat and was aged but not pasteurized.

In the work reported herein the viscosity of cream increased as the butterfat content increased. The higher the butterfat content the more marked was the increase in viscosity with further increase in fat content. This was true especially when the measurements were

made at a low temperature, for the viscosity of cream depends upon its temperature. The viscosity was lower at the higher temperatures. The decrease in viscosity was rapid until a temperature of about 32° C. (the melting point of butterfat) was reached. Heating the cream above the melting point of butterfat caused either a gradual decrease or practically no change in viscosity until a temperature of 80° was reached. At 80° a slight increase in viscosity took place. (Tables 1 and 2, and figs. 2 and 3.)

TABLE 1.—*Effect of butterfat content on the viscosity of raw cream at 20° C.*

Butterfat (per cent)	Relative viscosity	Butterfat (per cent)	Relative viscosity	Butterfat (per cent)	Relative viscosity
18	1.42	26	1.72	32	2.28
20	1.47	28	1.85	34	2.60
22	1.55	30	2.03	36	3.13
24	1.63				

TABLE 2.—*Effect of temperature on the relative viscosity of cream*

Temperature (°C.)	Relative viscosity of—			Temperature (°C.)	Relative viscosity of—		
	20 per cent cream	30 per cent cream	40 per cent cream		20 per cent cream	30 per cent cream	40 per cent cream
5	2.07	3.87	20.10	45	1.26	1.45	1.79
10	1.86	2.57	11.46	50	1.24	1.44	1.75
15	1.66	2.35	9.74				
20	1.51	2.03	4.82	55	1.24	1.42	1.71
25	1.40	1.81	3.29	60	1.24	1.41	1.68
				65	1.24	1.40	1.66
30	1.35	1.65	2.38	70	1.24	1.39	1.64
35	1.29	1.53	1.99	75	1.24	1.39	1.64
40	1.27	1.48	1.86	80	1.25	1.40	1.66

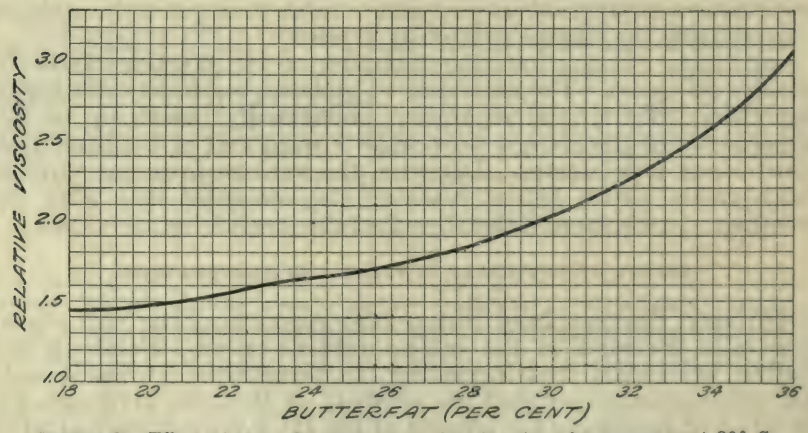


FIGURE 2.—Effect of butterfat content on the viscosity of raw cream at 20° C.

EFFECT OF AGE UPON VISCOSITY

Aging cream at a low temperature (5° C.) increased its viscosity. The greatest increase took place during the first 24 hours of aging, and at 48 hours the maximum was approached. A further, but very

gradual, increase in viscosity resulted from aging the cream longer than 48 hours. The increase in viscosity due to aging was greater for cream with a high butterfat content than for cream with a low butterfat content.

The increase in viscosity due to aging was greater with raw cream than with pasteurized cream. Pasteurizing the cream not only lowered the viscosity, but the effect of pasteurization was such that unless the cream had a high butterfat content, aging for 96 hours did not restore the cream to its original viscosity.

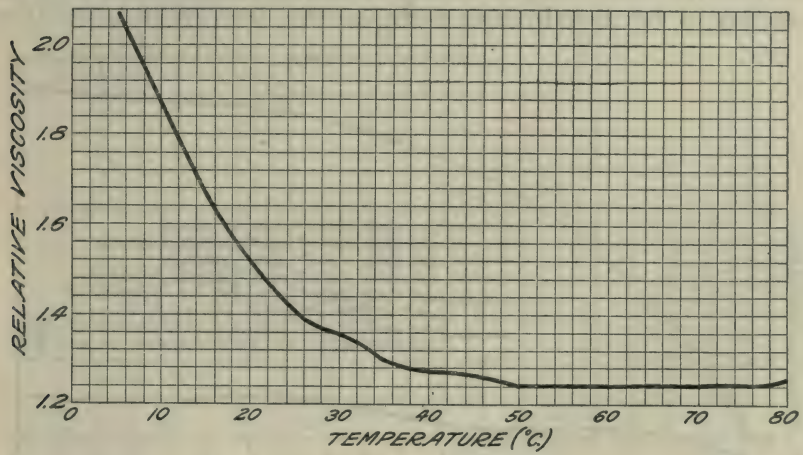


FIGURE 3.—Effect of temperature on the viscosity of 20 per cent cream

Homogenization increased the viscosity of both raw cream and pasteurized cream. The rate of increase in viscosity with age, however, was somewhat less for raw homogenized cream than for pasteurized unhomogenized cream. Contrary to the work of Sherwood and Smallfield (*17*), who state that the rate of increase in viscosity with age of a pasteurized homogenized cream is much greater than that of a pasteurized unhomogenized cream, the viscosity of pasteurized homogenized cream did not increase with age. (Table 3 and fig. 4.)

TABLE 3.—*Effect of age upon the relative viscosity of cream*

Character of cream	Butterfat	Temperature of cream	Relative viscosity					
			Fresh	At 3 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours
	Per cent	°C.						
Raw	20	5	1.70	1.80	1.98	2.05	2.14	2.21
Pasteurized	20	5	1.48	1.51	1.54	1.56	1.59	1.61
Raw	30	5	2.55	2.84	3.93	4.49	4.70	4.83
Pasteurized	30	5	2.35	2.44	2.56	2.67	2.75	2.79
Raw, homogenized at 2,000 pounds	20	20	2.12	----	2.13	2.14	2.15	2.19
Pasteurized, homogenized at 2,000 pounds	20	20	1.92	----	1.92	1.92	1.92	1.92

The increase in viscosity of cream with age was accompanied by an increase in the clumping of fat globules. The clumping of fat globules was slightly more pronounced in raw cream than in pasteurized cream; and the additional clumping of fat globules with age was more pronounced in raw cream. (Pls. 1 to 4, inclusive.)

The increase in viscosity due to the clumping of fat globules was reported by Babcock (*2*). He concluded that, although the globules in the clumps are not very firmly bound together, the clumps have, under ordinary conditions, sufficient stability to add very considerably to the consistency of milk. However, factors other than the clumping of fat globules may enter into the increase in viscosity of

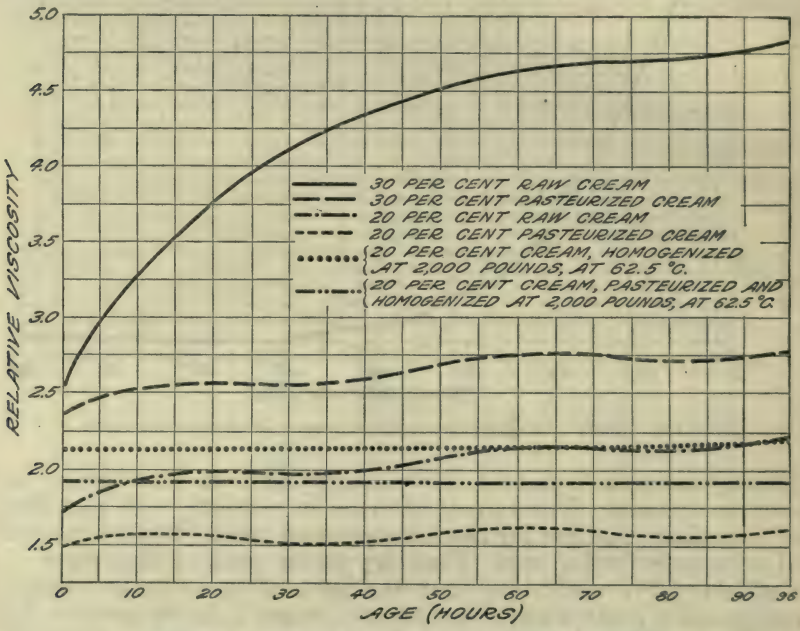


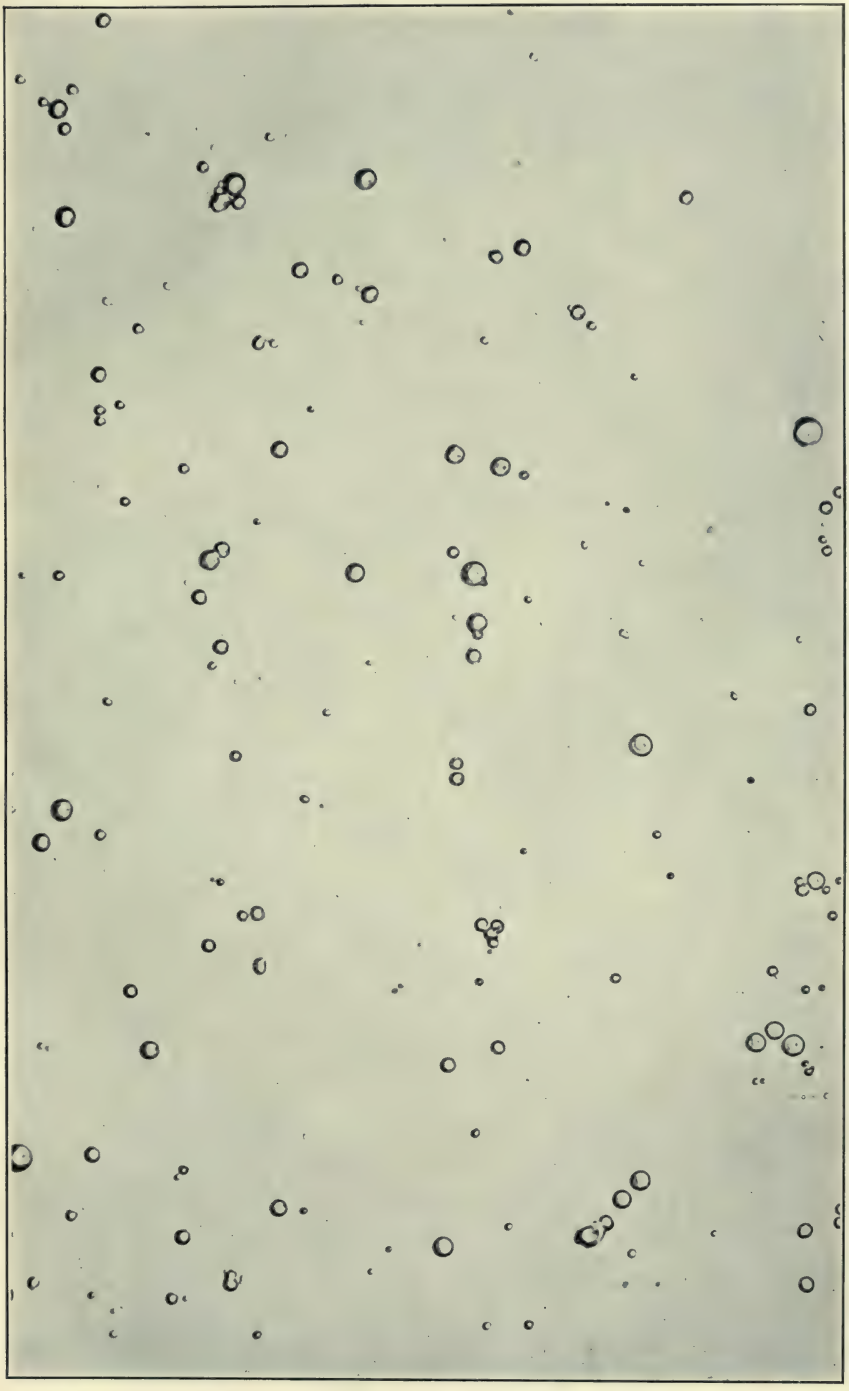
FIGURE 4.—Effect of age upon the viscosity of cream

cream with age, for Bateman and Sharp (*5*) found an increase in viscosity of skim milk with age; and Dahlberg and Hening (*8*) reported that aging greatly increased the viscosity of most of the rich cream and also had some effect even upon skim milk.

EFFECT OF PASTEURIZING TEMPERATURE

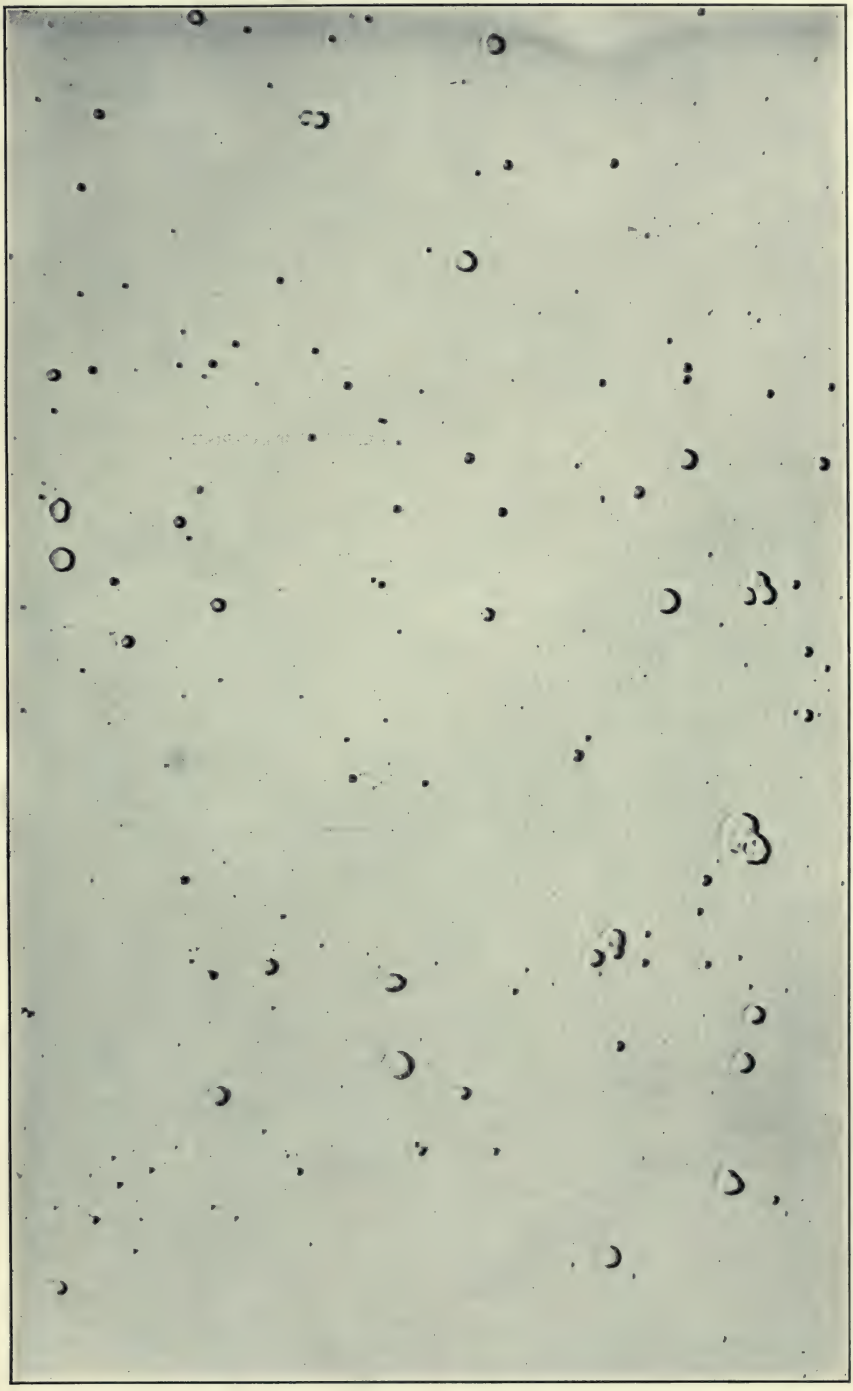
Babcock and Russell (*3*, *4*), Woll (*22*), Steiner (*18*), Evenson and Ferris (*13*), Dahlberg and Hening (*8*), Whitaker, Sherman, and Sharp (*20*), and others, found that the viscosity of milk and skim milk is lowered by pasteurization. Some of these investigators, however, reported an increase in viscosity at the higher pasteurizing temperatures. Achard and Stassano (*1*), disagreeing with the majority, reported a slight increase in the viscosity of milk when pasteurized.

The work of the present writer indicated that, although pasteurization lowered the viscosity of cream, the temperature at which the cream was pasteurized had but little effect upon viscosity. Cream

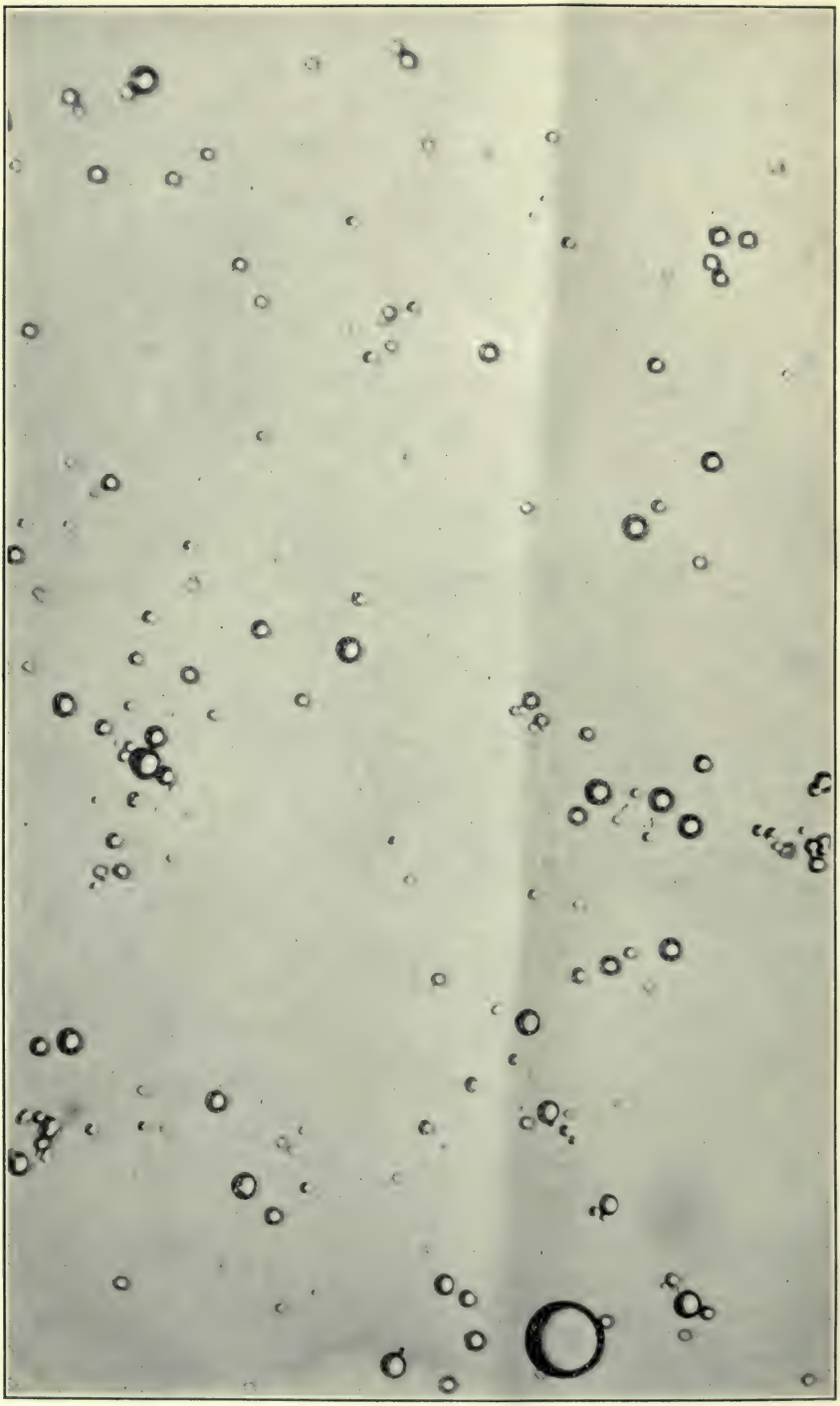


FAT GLOBULES IN FRESHLY SEPARATED 20 PER CENT RAW CREAM. × 500

FAT GLOBULES IN 20 PER CENT RAW CREAM AFTER AGING FOR 72 HOURS.
× 500



FAT GLOBULES IN FRESHLY PASTEURIZED 20 PER CENT CREAM. X 500



FAT GLOBULES IN 20 PER CENT PASTEURIZED CREAM AFTER AGING FOR 72 HOURS. × 500

with a butterfat content of 20 per cent had practically the same viscosity when pasteurized at 80° C. as when pasteurized at 62.5°. The effect of the pasteurizing temperature was somewhat more pronounced with cream having a butterfat content of 30 per cent than with cream containing only 20 per cent butterfat. With 30 per cent cream, however, the difference in the viscosity of cream pasteurized at 80°, as compared with cream pasteurized at 62.5°, was too small to be of practical importance. (Table 4 and fig. 5.)

TABLE 4.—*Effect of pasteurizing temperature upon the relative viscosity of cream*

Pasteurizing temperature °C.	Butterfat	Relative viscosity					
		Fresh	At 3 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours
	Per cent						
62.5	20	1.48	1.51	1.54	1.56	1.59	1.61
80	20	1.45	1.51	1.54	1.56	1.59	1.61
62.5	30	2.35	2.44	2.56	2.67	2.75	2.79
80	30	2.10	2.22	2.43	2.53	2.58	2.60

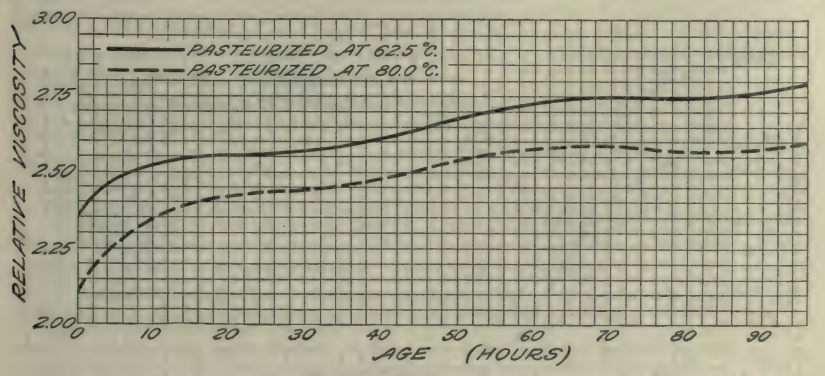


FIGURE 5.—Effect of pasteurizing temperature upon the viscosity of 30 per cent cream

GRAVITY-SEPARATED CREAM AND CENTRIFUGALLY SEPARATED CREAM COMPARED

The writer found gravity-separated cream to have a higher viscosity than centrifugally separated cream of the same butterfat content. The gravity cream was obtained by using a gravity-separation can 18 inches high and 8½ inches in diameter. The milk was held at a low temperature by placing the can in a large tank with sufficient ice and water around the can to extend above the height of the milk in the can. Samples of centrifugally separated cream and skim milk from the same mixed milk as was used in the separator can were suspended in the ice water, thus assuring the same storage conditions. The gravity-separated cream had an average butterfat content of 21.3 per cent. The centrifugally separated cream was standardized to the same butterfat content and the viscosity determinations were made 24 hours after the milk and cream were placed in the ice water.

Viscosity determinations at various temperatures (from 5° to 80° C.) showed the gravity-separated cream to have a slightly higher viscosity than centrifugally separated cream at the same temperatures. (Table 5 and fig. 6.) A microscopic study of the creams showed a greater degree of clumping of fat globules in the gravity-separated cream. This was probably due to the fact that the clumping of fat globules is closely associated with cream rising. The clumps thus formed during the 24-hour period of cream rising are more pronounced than those produced by centrifugal separation and subsequent aging for 24 hours.

TABLE 5.—*Viscosity of gravity-separated cream as compared with centrifugally separated cream*

Temperature (°C.)	Relative viscosity of—		Temperature (°C.)	Relative viscosity of—		Temperature (°C.)	Relative viscosity of—	
	Gravity cream	Separator cream		Gravity cream	Separator cream		Gravity cream	Separator cream
5	2.21	1.96	30	1.35	1.28	60	1.27	1.22
10	2.10	1.90	40	1.33	1.25	70	1.26	1.21
20	1.74	1.58	50	1.29	1.24	80	1.26	1.22

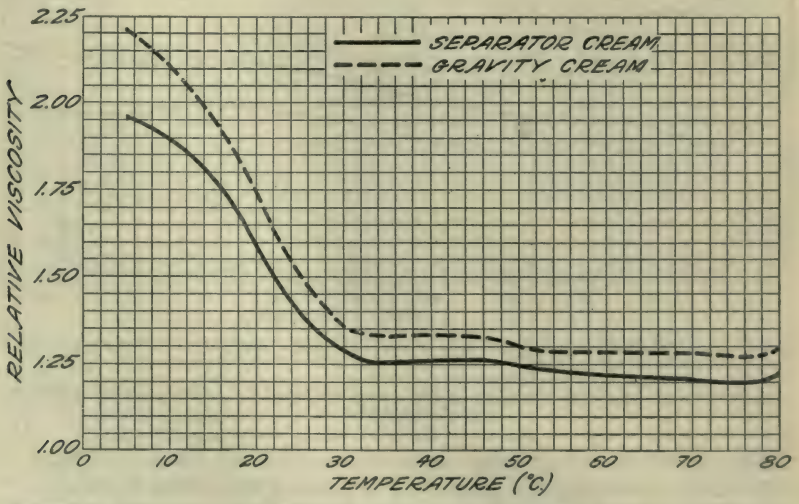


FIGURE 6.—Viscosity of gravity-separated cream as compared with centrifugally separated cream

EFFECT OF STANDARDIZATION

Standardizing cream to a specific butterfat content had practically no effect on viscosity, whether the cream was standardized from a higher to a lower, or from a lower to a higher butterfat content. (Table 6.) Cream with a butterfat content of 20 per cent had practically the same viscosity when prepared by standardizing with skim milk either cream which had an average butterfat content of 27.1 or 43.5 per cent. A mixture of milk and cream with an average butterfat content of 13 per cent standardized to 20 per cent

with cream having an average butterfat content of 34.7 per cent had a slightly higher viscosity than cream containing a higher butterfat content standardized to 20 per cent with skim milk. The difference in viscosity, however, was so small as to be of no practical importance. (Table 6.)

TABLE 6.—*Effect of standardization upon the viscosity of 20 per cent cream*

Preparation of cream		Relative viscosity at temperature of —								
Standardized from—	Standardized with—	5° C.	10° C.	20° C.	30° C.	40° C.	50° C.	60° C.	70° C.	80° C.
27.1 per cent cream	Skim milk	1.78	1.69	1.44	1.36	1.28	1.25	1.24	1.23	1.23
43.5 per cent cream	do	1.76	1.63	1.41	1.33	1.27	1.23	1.23	1.22	1.22
13.0 per cent cream	34.7 per cent cream	1.82	1.70	1.49	1.42	1.32	1.29	1.27	1.26	1.26

EFFECT OF FREEZING

Investigators agree that the effect of freezing upon normal cream is mainly that of destroying its physical structure, especially that of the fat system. A separation of free fat results and this becomes more marked with an increase in the fat concentration. Bateman and Sharp (*5*) found that frozen skim milk held for one day decreased in viscosity, but after it had aged in the frozen state for several days the viscosity increased to nearly that of the fresh sample.

In the work reported here the relative viscosity of cream with a fat content of 20 per cent was lowered 4.05 per cent by freezing. It was necessary to thaw the cream slowly and at a temperature just above the melting point of the fat, in order to prevent the flaking of protein and separation of free fat. Frozen cream with a fat content of 30 per cent could not be thawed without separation of fat to such an extent that accurate viscosity measurements were impossible. The viscosity of 20 per cent cream which had been frozen increased slightly upon aging. Aging for 96 hours increased the relative viscosity only 4.82 per cent (when the viscosity determinations were made at 5° C.) as compared with an increase of 30 per cent for similar cream which had not been frozen. Microscopic examination showed that regardless of age the fat globules remained separate and distinct, indicating that the ability of the globules to coalesce had been destroyed.

EFFECT OF ACIDITY

Increasing the acidity up to and including 0.3 per cent had practically no effect on the viscosity of 20 per cent raw cream. When the viscosity determinations were made at 5° C., an increase in acidity from an average of 0.202 per cent to an average of 0.254 per cent slightly increased the viscosity, but a further increase in acidity to an average of 0.3 per cent resulted in no additional increase in viscosity. When the determinations were made at 30°, increasing the acidity of the cream to 0.3 per cent had no effect on viscosity. At 62.5°, increasing the acidity to 0.254 per cent had no effect on viscosity, but a further increase in acidity to 0.3 per cent resulted in a slight increase in viscosity. (Table 7 and fig. 7.)

TABLE 7.—*Effect of acidity upon the viscosity of 20 per cent raw cream*

Acidity (per cent)	Relative viscosity at—		
	5° C.	30° C.	62.5° C.
0.202	2.01	1.31	1.22
.254	2.11	1.32	1.22
.300	2.12	1.32	1.27

It therefore appears that acidity up to and including 0.3 per cent has practically no effect upon the viscosity of normal cream. This is in agreement with results obtained by Doan (*12*), who reports that changes in the acidity of the plasma had but little influence upon the clumping tendencies of fat exhibited in mixtures of normal milk and cream when homogenized.

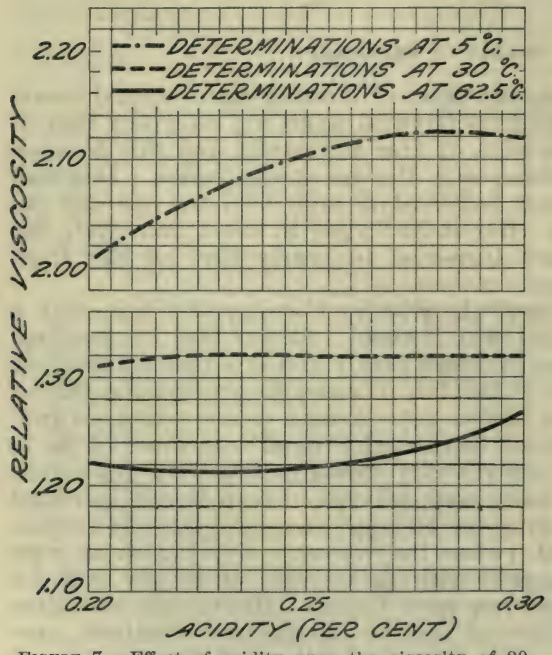


FIGURE 7.—Effect of acidity upon the viscosity of 20 per cent raw cream

EFFECT OF COOLING

The viscosity of cream is affected by the rate of cooling. When raw cream with a butterfat content of 20 per cent was permitted to cool slowly, by packing in ice, from a separating temperature of 26° to 5° C., the relative viscosity was 1.71 per cent higher at 5° and 1.82 per cent higher at 10° than the viscosities obtained at these temperatures for similar cream cooled rapidly with a surface cooler. Cream with a butterfat content of 30 per cent, which was cooled slowly, had a relative viscosity higher by 2.47 per cent and 1.82 per cent at 5° and 10°, respectively, than the rapidly cooled cream.

The slow cooling of pasteurized cream from a pasteurizing temperature of 62.5° to a temperature of 5° C. had a more pronounced effect on viscosity than did the slow cooling of raw cream. Pasteurized cream with a butterfat content of 20 per cent, when cooled slowly, had a relative viscosity 3.13 per cent higher at 5° C. and 2 per cent higher at 10° than similar cream cooled rapidly. Pasteurized cream with a butterfat content of 30 per cent, when cooled slowly, had a relative viscosity higher by 5.18 per cent and 3.5 per cent at 5° and 10°, respectively, than had similar cream when cooled rapidly.

Pasteurized cream with a butterfat content of 30 per cent, when cooled slowly from a pasteurizing temperature of 62.5° to 45° C. and then cooled rapidly to 5°, had a relative viscosity 1.21 per cent higher at 5° and 0.84 per cent higher at 10° than when the cream was cooled rapidly from the pasteurizing temperature to 5°. When the cream was cooled slowly to 30° and then rapidly to 5°, its relative viscosity was 3.93 per cent and 2.68 per cent greater at 5° and 10°, respectively, than when the cream was cooled rapidly.

The cooling of fresh raw cream just before pasteurizing had practically no effect on the relative viscosity of the pasteurized cream. Cream with a butterfat content of 30 per cent cooled to 5° C. before pasteurizing had a relative viscosity only 0.39 per cent greater at 5° and only 0.89 per cent greater at 10° than similar cream not cooled below the separating temperature before pasteurizing.

These results indicate that where cream with a high viscosity is desirable the better method is to cool the cream slowly. This applies to the cooling of raw cream and to an even greater extent to the cooling of pasteurized cream. In the case of pasteurized cream, partial cooling at a slow rate followed by rapid cooling also increases the viscosity as compared to rapid cooling. Whittaker, Archibald, Shere, and Clement (*21*) found that milk cooled in tank or vat pasteurizers from the pasteurizing temperature to 10° C. showed a small cream volume. Cooling milk in the tank or vat to approximately 45° and then cooling it quickly to below 10° over a separate cooler resulted in a large cream volume. The small cream volume on the milk which was cooled slowly may have been due to the amount of agitation necessary to prevent the formation of a cream layer during the cooling period. In the experiments reported here, cream which was cooled slowly was not agitated while cooling.

A microscopic study of the cream showed that the fat globules were clumped to a greater extent in cream which was cooled slowly than in cream which was cooled rapidly. The increase in relative viscosity due to cooling the cream slowly to 45° C. indicates that the clumping of fat globules takes place, at least to a slight degree, above this temperature. The greater increase in relative viscosity with slow cooling to a lower temperature also indicates that clumping takes place to a more marked degree at temperatures below 45°. The rapid cooling does not allow enough time for the fat globules to clump to a marked degree, and the sudden cooling to a low temperature apparently has a tendency to harden the globules and to destroy their ability to coalesce.

EFFECT OF SEPARATING TEMPERATURE

Dahlberg and Hening (*8*) demonstrated that the viscosity of cream of any percentage of fat could be greatly altered by the condition of the fat at the time of separation. The writer's work showed that the viscosity of cream is affected by the temperature at which the cream is separated. Raw cream with a butterfat content of 30 per cent, separated from milk at 18° C., had a relative viscosity 14.45 per cent higher at 5°, and 10.24 per cent higher at 10° than cream at these temperatures which had been separated from similar milk at 36°.

EFFECT OF STORAGE OF MILK

The viscosity of raw cream is affected by the time and temperature of storage of the milk before separation. Raw cream with a butterfat content of 30 per cent, separated from milk which had been stored three hours at 4° C. had a relative viscosity 14.16 per cent higher at 5°, and 12.23 per cent higher at 10° than cream which was separated from similar milk stored at 18° for three hours. When the milk was stored for 12 hours before separation, the cream from that stored at 4° C. had a relative viscosity 12.2 per cent and 9.65 per cent higher at 5° and 10°, respectively, than cream from the milk stored at 18°.

When the milk was stored at 4° C., increasing the time of storage before separation from 3 hours to 12 hours increased the relative viscosity of the cream 4.96 per cent at 5°, and 2.17 per cent at 10°. When the storage temperature was 18°, increasing the time of storage from 3 hours to 12 hours increased the relative viscosity of the cream 6.8 per cent and 4.28 per cent at 5° and 10°, respectively.

The increase in viscosity of raw cream due to storage conditions was not entirely lost when the cream was pasteurized. Pasteurized cream with a butterfat content of 30 per cent from milk which had been stored at 4° C. for 12 hours had a relative viscosity 3.52 per cent higher at 5°, and 3.22 per cent higher at 10° than when the cream was obtained from similar milk stored at 18° for 12 hours. The decrease in relative viscosity due to pasteurization was 44.44 per cent at 5°, and 40.26 per cent at 10° for the cream separated from milk which had been stored for 12 hours at 4°, as compared with 39.79 per cent and 36.55 per cent at 5° and 10°, respectively, for the cream separated from milk which was stored for 12 hours at 18°.

Therefore it appears that one of the best methods to increase the viscosity of cream is to store the milk at a low temperature for at least 12 hours before separation. This is in accord with the work of Dahlberg and Hening (*8*), who found that it was possible, by controlling the extent of fat clumping before separation, to produce raw cream that resembled ordinary pasteurized cream, or to produce raw cream that had about 10 times the viscosity that ordinary pasteurized cream has after aging. They further found that it was possible to produce cream from pasteurized milk that resembled very viscous raw cream. Pyne and Lyons (*15*) obtained the same or better results by storing cream at a low temperature and then reseparating it.

EFFECT OF PASTEURIZING BEFORE SEPARATING

The effect that pasteurizing milk before it is separated has upon the viscosity of the cream depends upon the manner of handling the pasteurized milk. Cream with a butterfat content of 30 per cent from milk pasteurized and separated without cooling had a relative viscosity, at 24 hours of age, 8.85 per cent lower at 5° C., and 9.24 per cent lower at 10° than similar cream separated from similar milk at 26° and pasteurized after being separated. After aging for 48 hours, the cream from the milk pasteurized before being separated had a relative viscosity 9.56 per cent and 8.06 per cent lower at 5° and 10°, respectively, than the cream pasteurized after it was separated.

Cream with a butterfat content of 30 per cent from milk pasteurized and rapidly cooled (by use of a surface cooler) to a separating tem-

perature of 26° C. had a relative viscosity at 24 hours of age 4.63 per cent lower at 5° and 4.24 per cent lower at 10° than cream separated from similar milk but pasteurized after being separated. After aging for 48 hours, the cream from the milk pasteurized before being separated had a relative viscosity 4.07 per cent and 3.66 per cent lower at 5° and 10°, respectively, than the cream pasteurized after it was separated.

Cream with a butterfat content of 30 per cent separated from milk pasteurized and cooled slowly (with cold water) in the vat before it was separated, to a separating temperature of 26° C. had a relative viscosity at 24 hours of age 5.75 per cent greater at 5°, and 7.56 per cent greater at 10° than cream separated from similar milk and pasteurized after it was separated. After aging for 48 hours the cream from milk pasteurized before it was separated had a relative viscosity 5.2 per cent and 6.07 per cent greater at 5° and 10°, respectively, than the cream pasteurized after it was separated.

These results indicate that when milk is separated after pasteurization and a cream with good viscosity is desired, the milk should be cooled slowly with minimum agitation to the separating temperature. However, Dahlberg and Hening (*8*) have shown that cream of great viscosity can not be produced without giving the fat time to harden after pasteurization and before the milk is separated.

EFFECT OF HOMOGENIZATION

Homogenization increases the viscosity of cream. When cream with a butterfat content of 20 per cent was homogenized its viscosity was increased. The increase in viscosity was in direct relation to the pressure used for homogenization. (Table 8 and fig. 8.) Burgwald (*6*) and Webb and Holm (*19*) found that the feathering of cream is affected to a considerable extent by homogenization. Therefore when cream is homogenized for the purpose of increasing its viscosity, especially if the cream is to be used as coffee cream, care should be taken that the increase in viscosity is not obtained at the expense of increasing the feathering.

TABLE 8.—*Effect of homogenization upon the viscosity of cream with a butterfat content of 20 per cent at 20° C.*

Homogenizing pressure (pounds per square inch)	Relative viscosity of cream pasteurized and homogenized at—		Homogenizing pressure (pounds per square inch)	Relative viscosity of cream pasteurized and homogenized at—	
	62.5° C.	70° C.		62.5° C.	70° C.
0	1.34	1.37	2,000	2.07	1.60
500	1.41	1.39	2,500	2.26	1.69
1,000	1.50	1.47	3,000	2.70	1.73
1,500	1.77	1.55			

Doan (*11*), Mortensen (*14*), Mortensen, as reported by Curtiss (*7*), Evenson and Ferris (*13*), Dahle and Martin (*9*), Reid and Moseley (*16*), and others have called attention to the fact that homogenization of cream and of ice-cream mixes causes not only a subdivision of the fat globules but also their aggregation into clumps.

In a microscopic study of homogenized cream made by the writer, homogenizing at a pressure of 500 pounds per square inch not only broke up the individual fat globules but caused a wide dispersion of the newly formed globules. When the pressure was increased to 1,000 pounds per square inch the fat globules were broken up to a greater extent, and many of the dispersed globules were brought together into small clumps, most of which consisted of two to four globules. As the pressure increased the clumps increased in size, and the number and size of the individual globules became smaller.

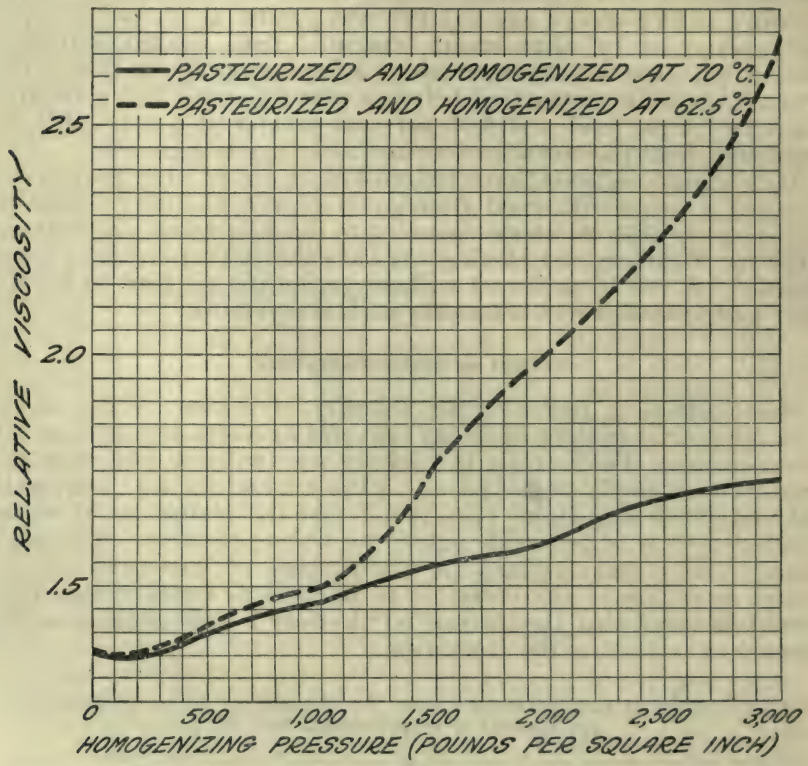
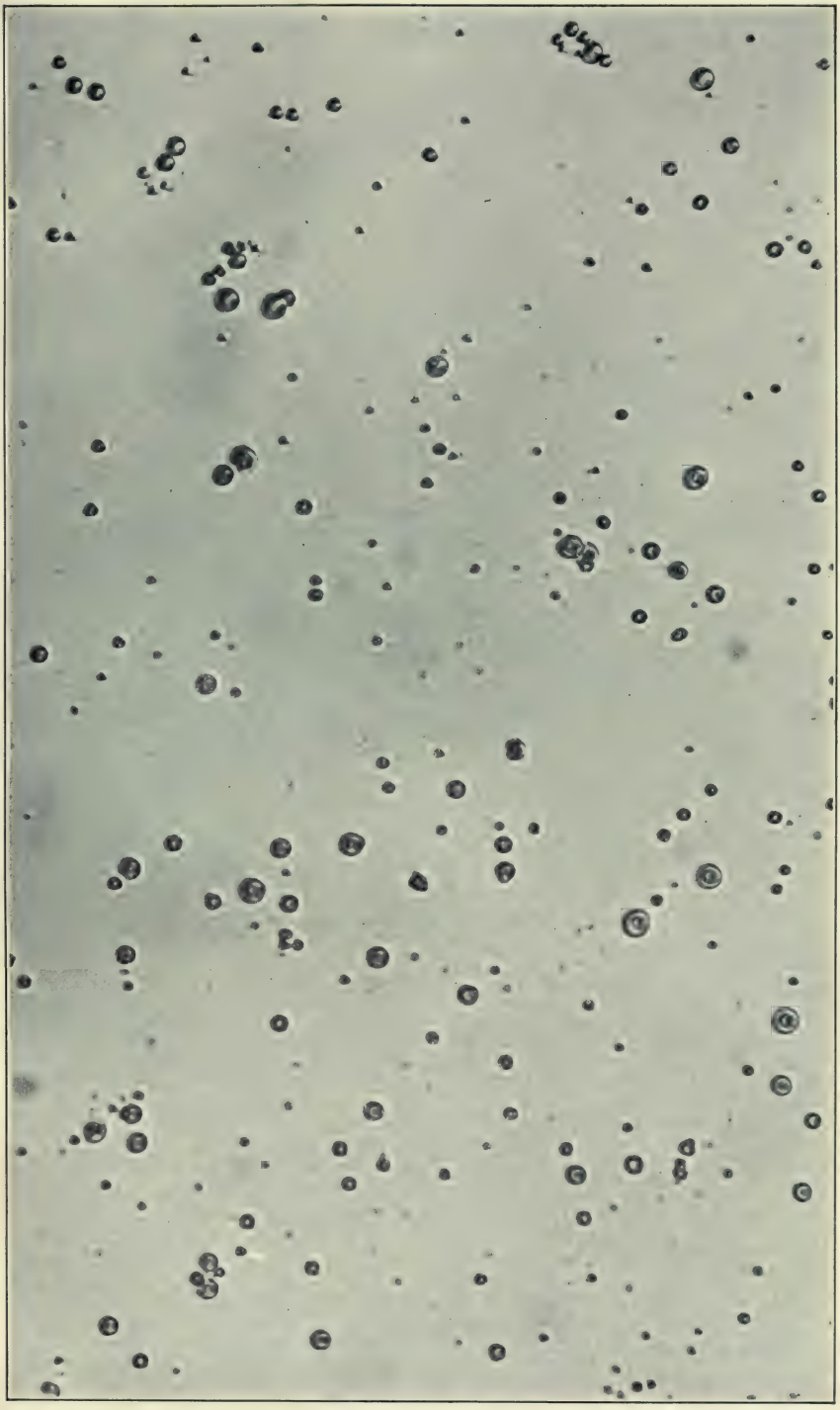


FIGURE 8.—Effect of homogenization upon the viscosity of pasteurized cream with a butterfat content of 20 per cent

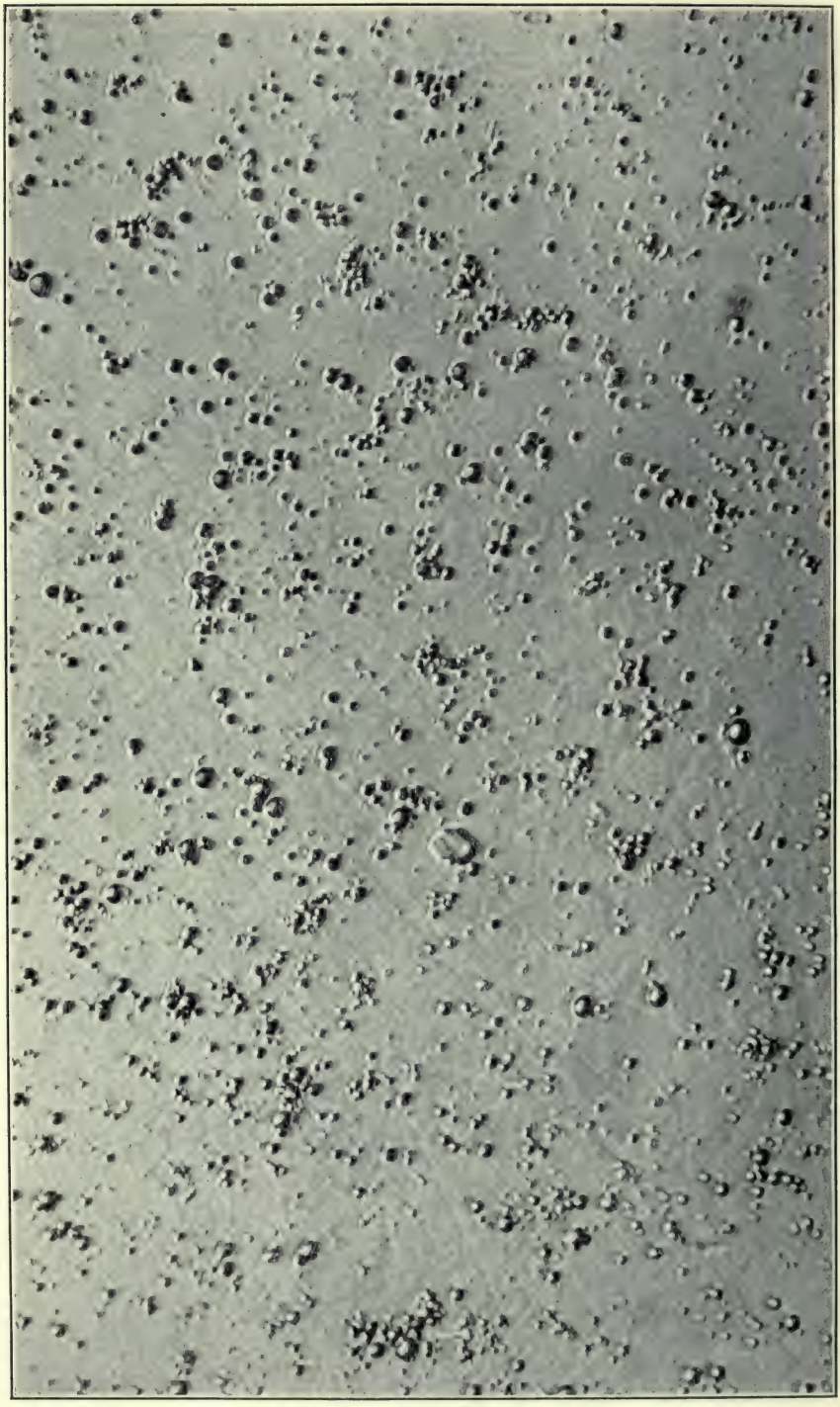
At about 2,500 pounds pressure the clumps reached maximum size. Increasing the pressure above this point had a tendency not only to diminish the number of individual globules but also to break up the larger clumps into smaller ones, and when 4,000 pounds pressure was applied a large percentage of the globules were in dense, medium-sized clumps. (Pls. 5 to 10, inclusive.)

EFFECT OF HOMOGENIZING TEMPERATURE

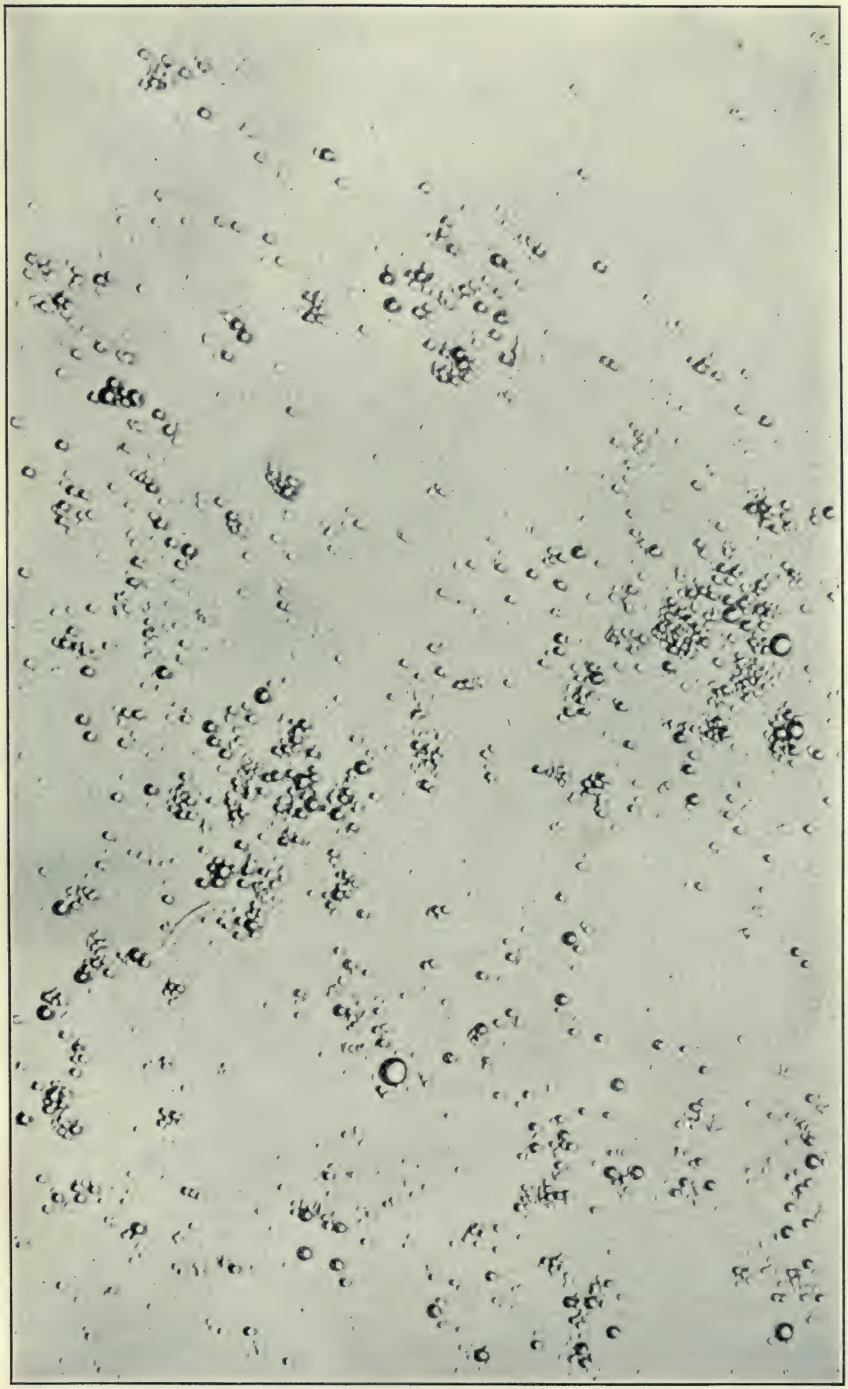
The temperature at which cream is homogenized affects its viscosity. When pasteurized cream with a butterfat content of 20 per cent



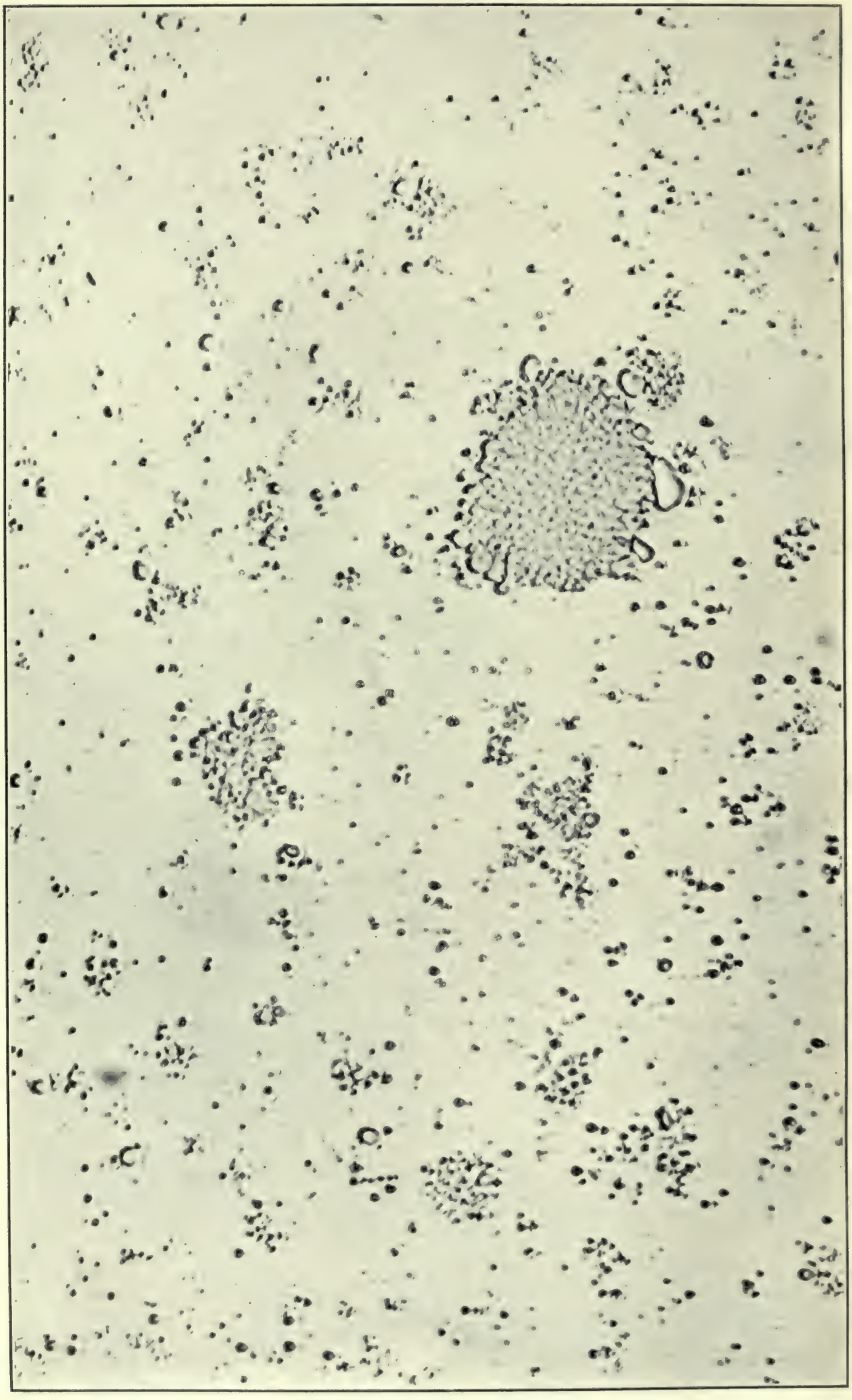
FAT GLOBULES IN 20 PER CENT CREAM PASTEURIZED AT 62.5° C. X 500



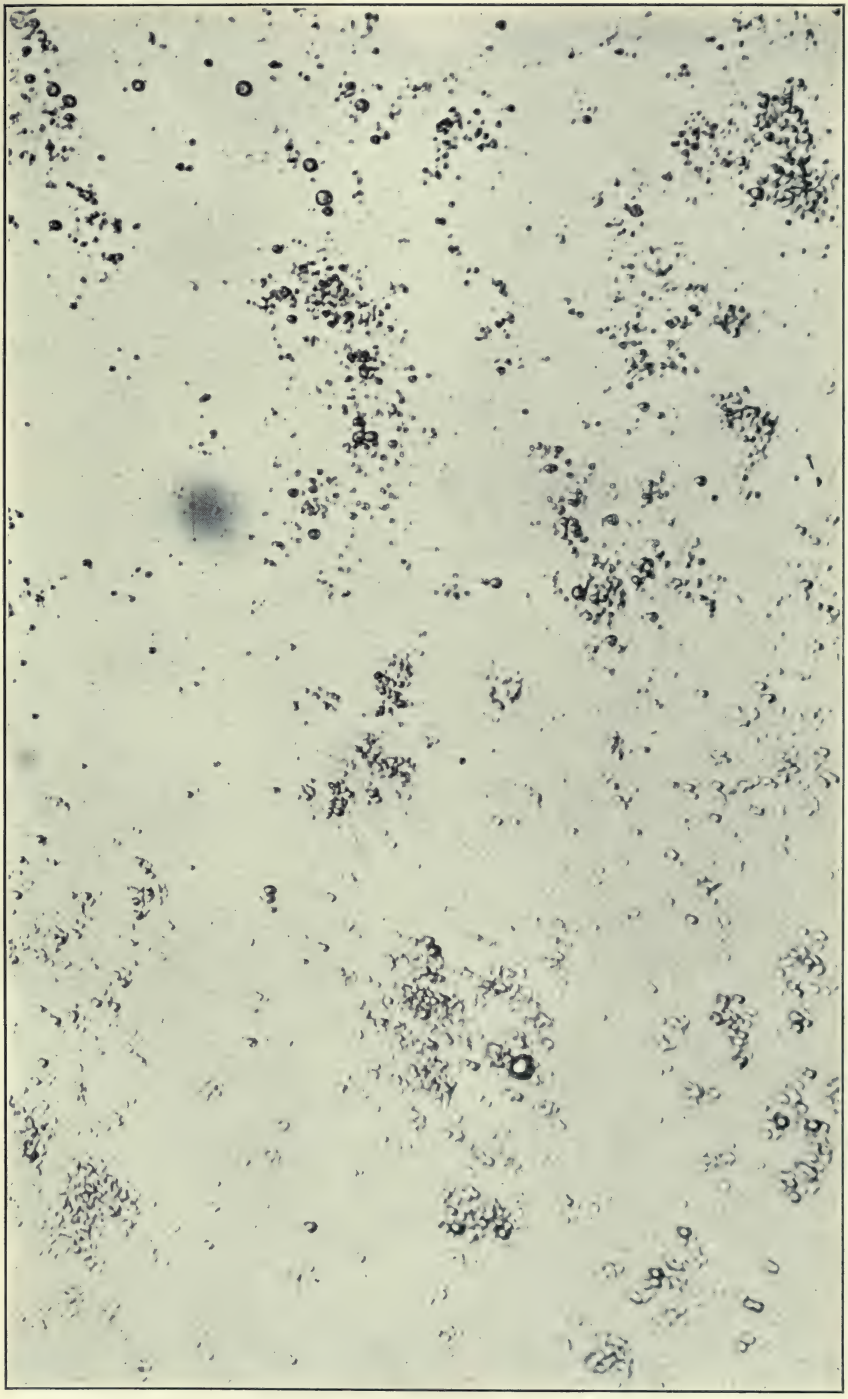
SAME CREAM AS IN PLATE 5, HOMOGENIZED AT 500 POUNDS PRESSURE PER SQUARE INCH, AT 62.5° C. × 500



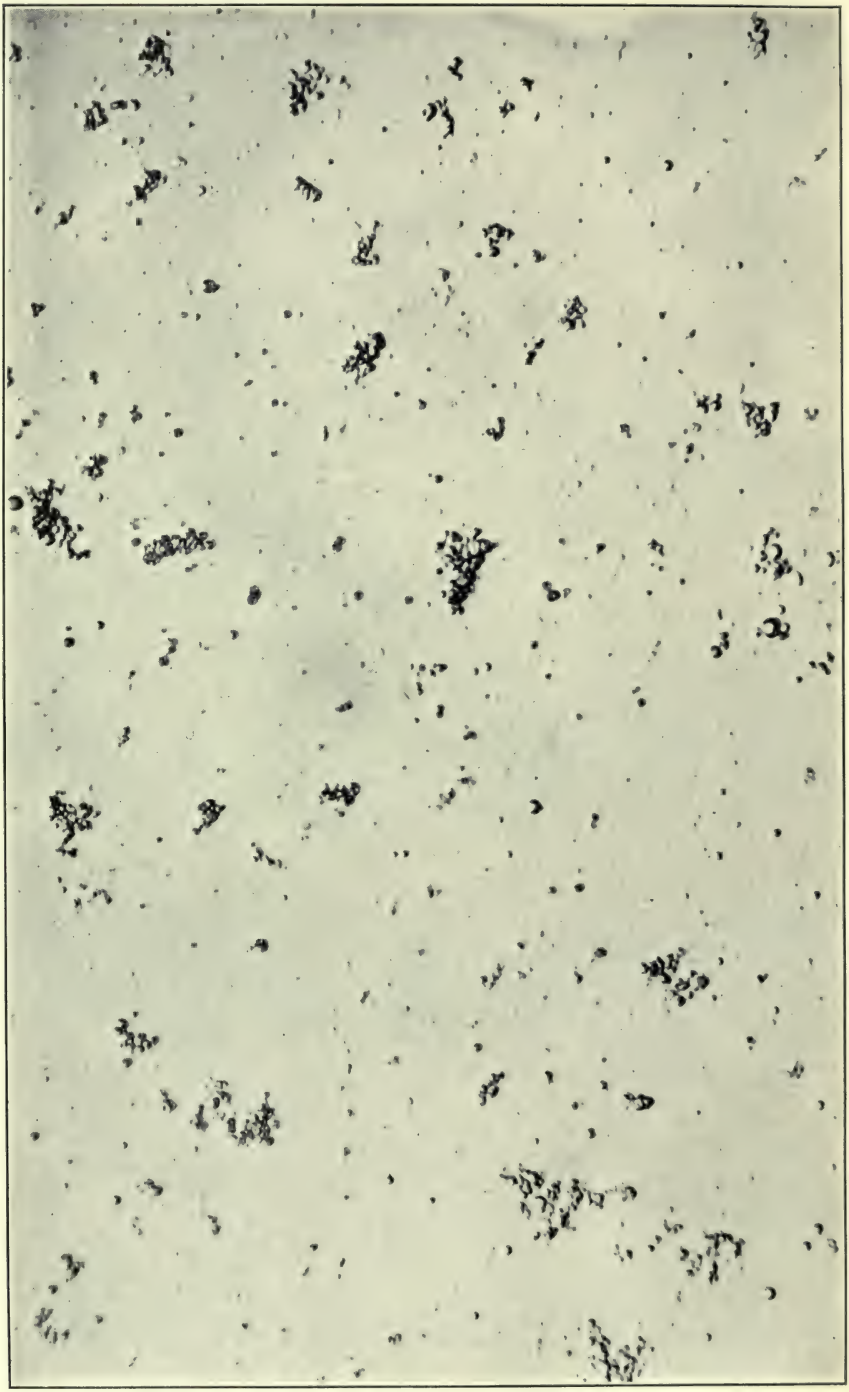
SAME CREAM AS IN PLATE 5, HOMOGENIZED AT 1,000 POUNDS PRESSURE PER SQUARE INCH, AT 62.5° C. X 500



SAME CREAM AS IN PLATE 5, HOMOGENIZED AT 2,000 POUNDS PRESSURE PER SQUARE INCH, AT 62.5° C. × 500



SAME CREAM AS IN PLATE 5, HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH, AT 62.5° C. X 500



SAME CREAM AS IN PLATE 5, HOMOGENIZED AT 4,000 POUNDS PRESSURE PER SQUARE INCH, AT 62.5° C. × 500

was homogenized at a constant pressure, but at temperatures varying from 50° to 88° C., its relative viscosity varied with the temperature. The lower the temperature at which the cream was homogenized, the higher was the viscosity. When different samples of the cream were pasteurized at the same temperatures as those at which they were homogenized, as the temperature was increased the relative viscosity decreased until it was at its minimum at 70°, and then increased with a further rise in the homogenizing temperature. When the cream was pasteurized at a constant temperature of either 62.5° or 80° and the homogenizing temperature was varied, the maximum viscosity in both cases was obtained at the lowest homogenizing temperature. However, the higher pasteurizing temperature, 80°, gave a lower maximum viscosity than did the lower temperature, 62.5°. This indicates that the relative viscosity of homogenized cream is slightly affected by the temperature at which it was pasteurized. For the constant pasteurizing temperatures used, the homogenizing temperature at which the lowest viscosity resulted ranged from 70° to 80°. Raising the temperature of homogenization to 88° increased the relative viscosity above the minimum. (Table 9 and fig. 9.)

TABLE 9.—*Effect of homogenizing temperature upon the viscosity of pasteurized cream with a butterfat content of 20 per cent*

Homogenizing temperature (°C.)	Relative viscosity of—			
	Cream pasteurized at homogenizing temperature; homogenized at 3,000 pounds	Cream pasteurized at homogenizing temperature; homogenized at 2,000 pounds	Cream pasteurized at 62.5° C.; homogenized at 2,000 pounds	Cream pasteurized at 80° C.; homogenized at 2,000 pounds
50	4.6	3.3	3.2	2.9
62.5	3.6	2.6	2.6	2.4
70	2.1	1.6	2.0	2.0
80	2.3	1.8	1.7	1.8
88	3.1	2.1	1.9	2.0

In determining the temperature at which cream should be homogenized, the fact that the stability of homogenized cream is in indirect proportion to its viscosity, as has been reported by Webb and Holm (*19*), should not be overlooked.

In the present work a microscopic study of cream homogenized at different temperatures from 50° to 88° C. showed that the clumping of the fat globules was affected by the temperature of homogenization. The greater degree of clumping took place at the lower homogenizing temperatures. With rise in temperature the degree of clumping diminished until the point was reached where the viscosity was the lowest, and at this point the fat globules were widely dispersed, but with further rise in temperature the degree of clumping increased. (Pls. 11 to 15, inclusive.)

EFFECT OF REHOMOGENIZATION

The viscosity of homogenized cream is lowered by rehomogenization. The relative viscosity of cream with a butterfat content of 20 per cent, homogenized at a temperature of 62° C. and a pressure of 2,000 pounds was lowered 18.42 per cent by rehomogenization at the same temperature and pressure.

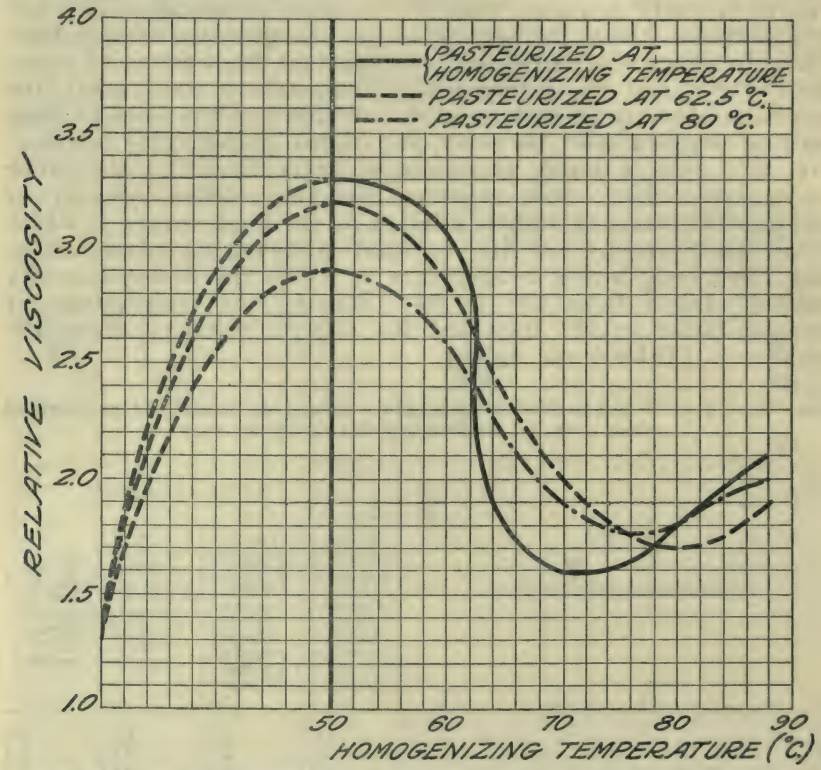


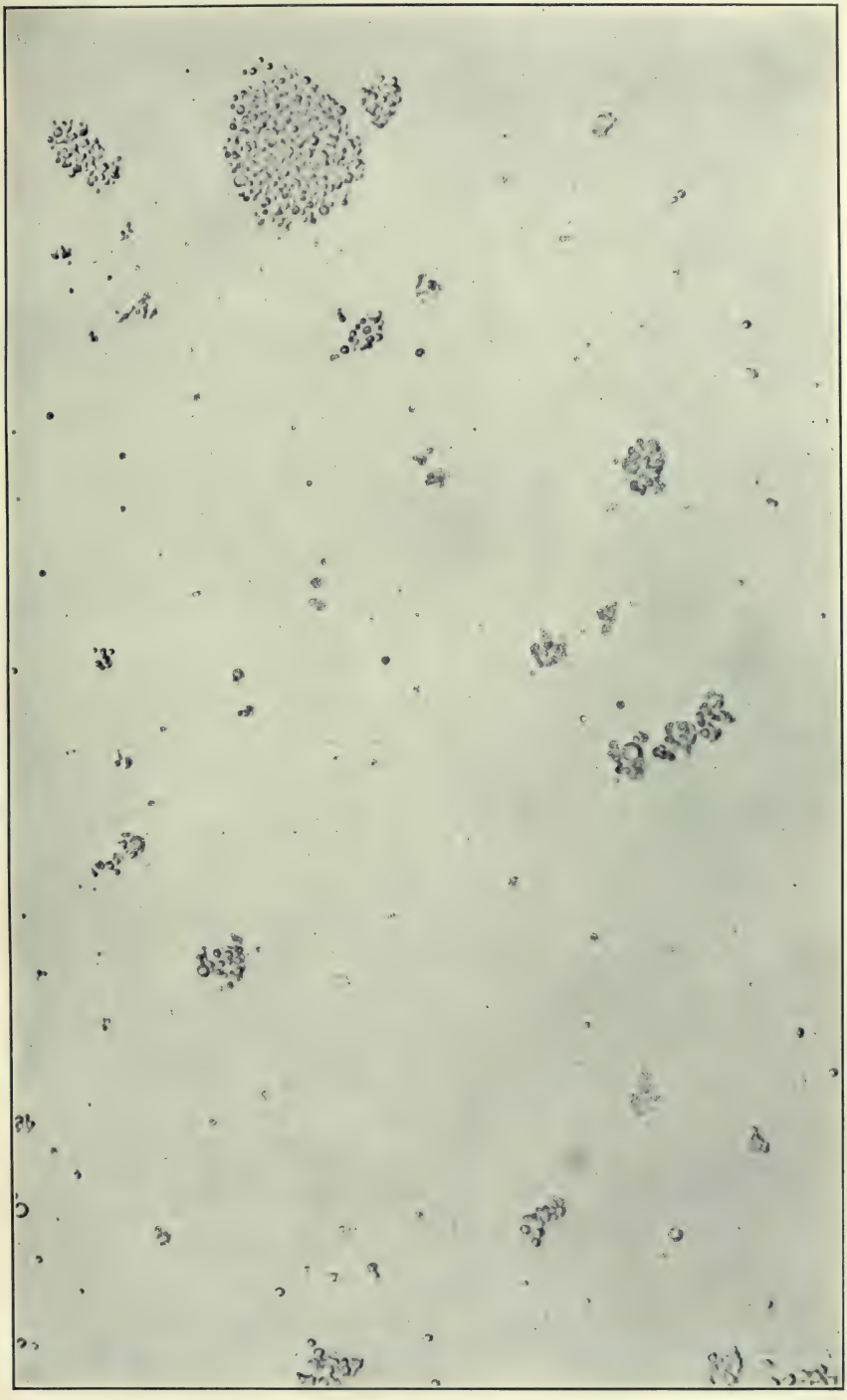
FIGURE 9.—Effect of homogenizing temperature upon the viscosity of 20 per cent cream homogenized at 2,000 pounds per square inch

A miscroscopic study of the fat globules in the processed creams showed that upon rehomogenization of the cream many of the clumps due to homogenizing were broken up when the cream was homogenized a second time. (Pls. 16 and 17.)

EFFECT OF SOLIDS NOT FAT

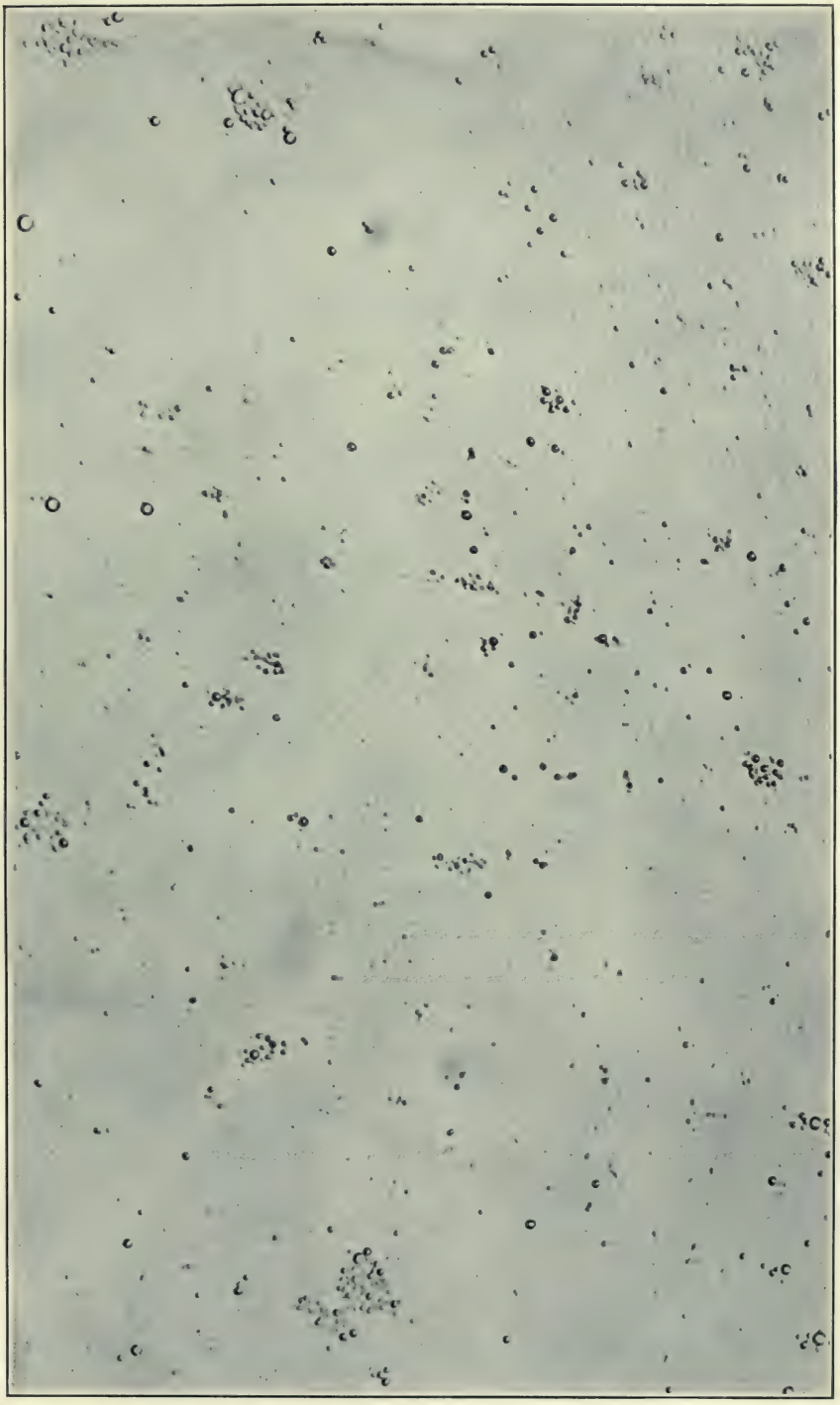
Dahlberg and Hening (*8*) found that small variations in the milk solids not fat in cream did not materially affect viscosity. Doan (*12*), however, reported that the ratio of the amount of plasma solids to the amount of fat in the mixtures processed is a limiting factor in the fat-clumping phenomenon.

The work of the writer indicates that the viscosity of cream is affected by the percentage of solids not fat present. When cream with a butterfat content of 36 per cent was standardized to a butterfat content of 20.5 per cent with skim milk, water, or evaporated skim milk, so as to vary the percentage of solids not fat, the viscosity of the cream also varied. The lower the percentage of solids

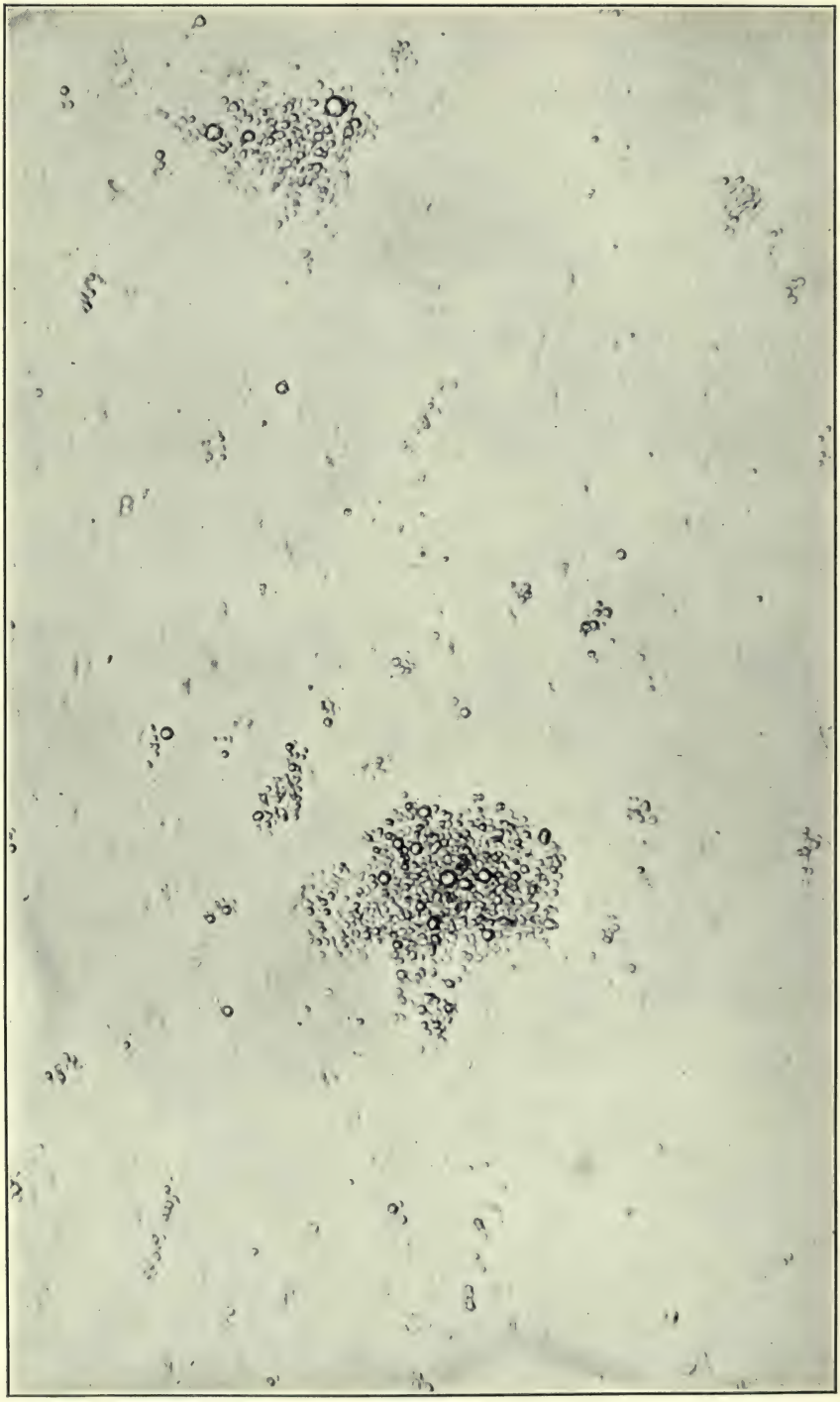


TWENTY PER CENT CREAM PASTEURIZED AT 50° C. AND HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH AT 50° C. X 500

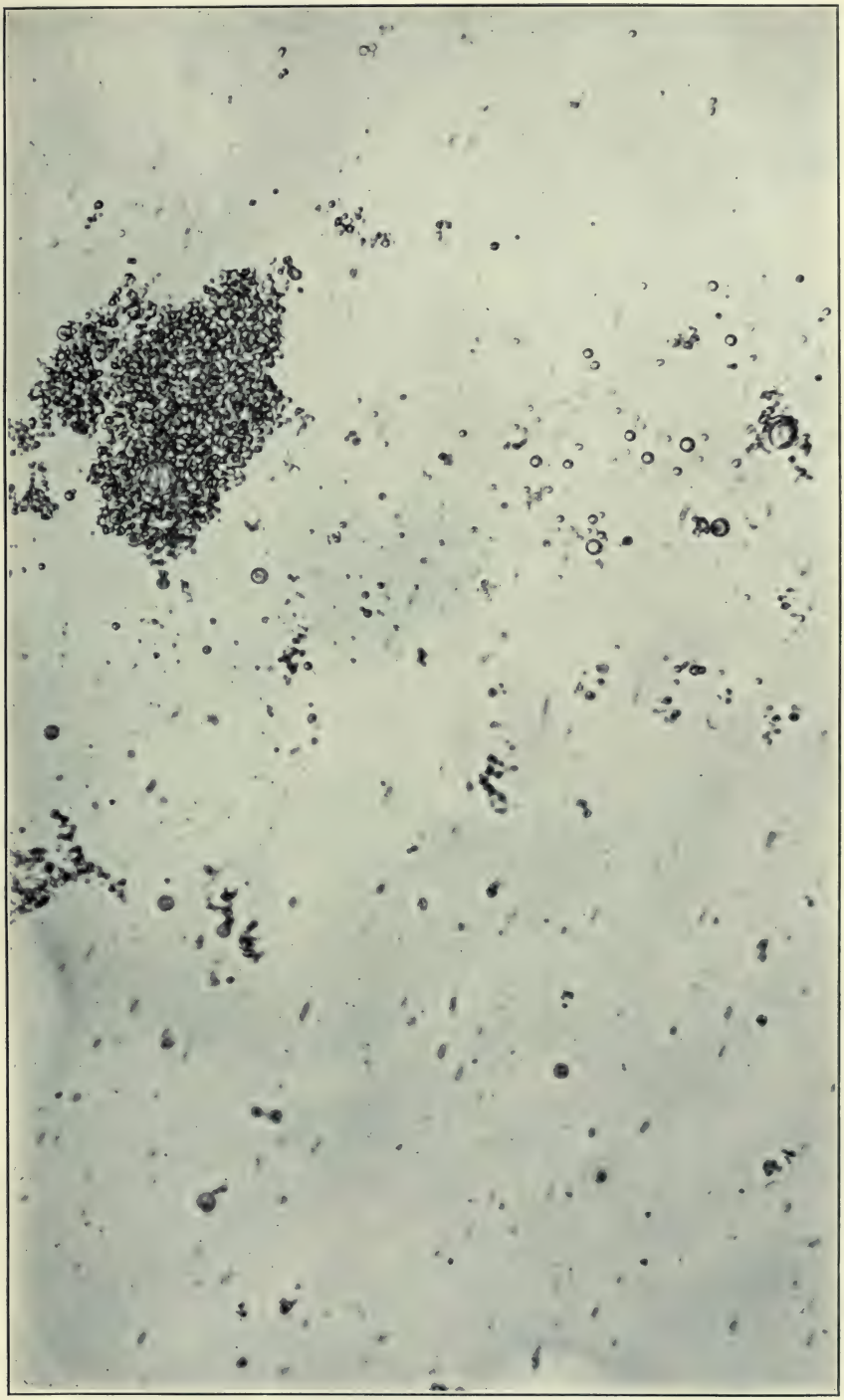
TWENTY PER CENT CREAM PASTEURIZED AT 62.5° C. AND HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH AT 62,5° C. × 500



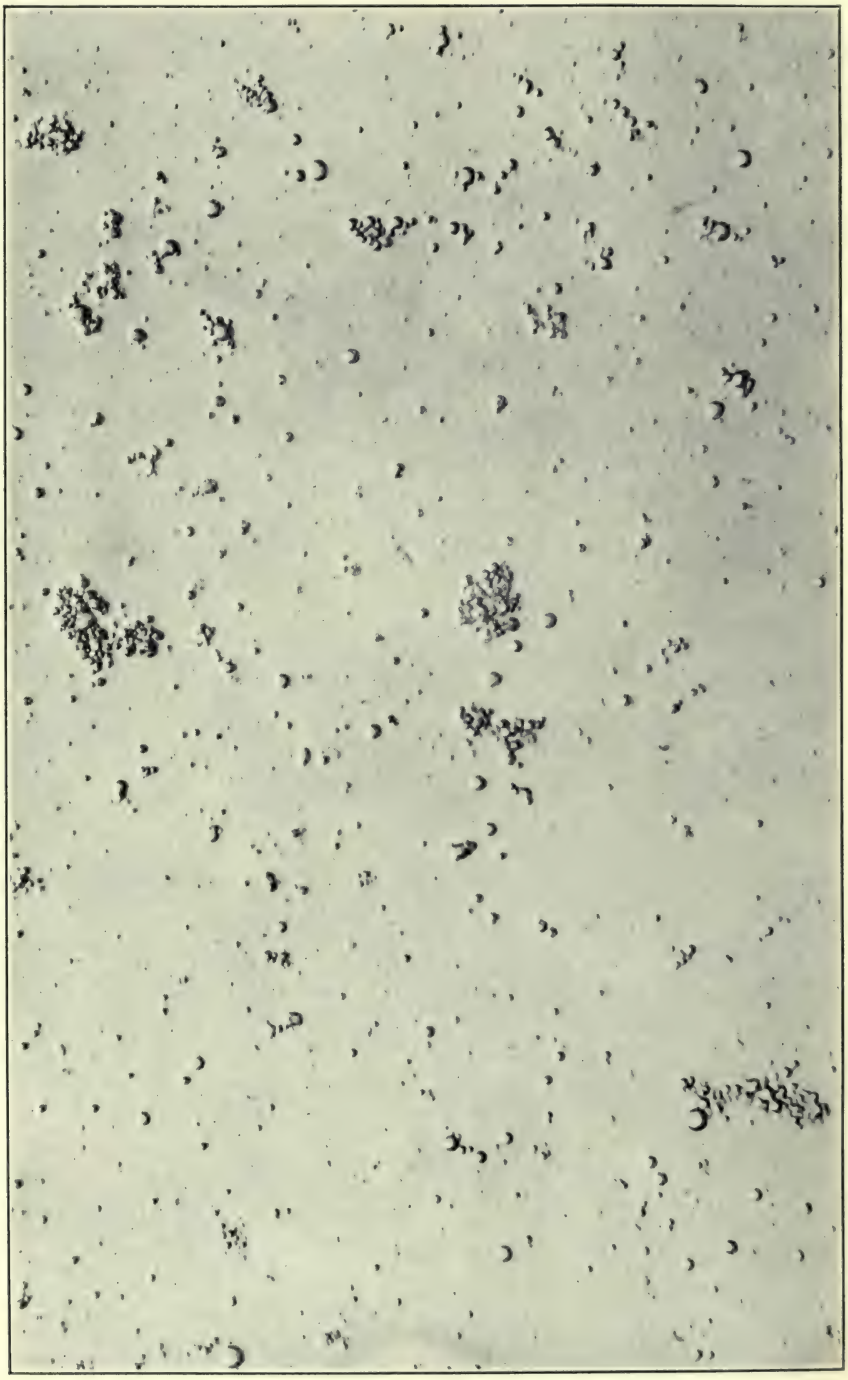
TWENTY PER CENT CREAM PASTEURIZED AT 70° C. AND HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH AT 70° C. × 500



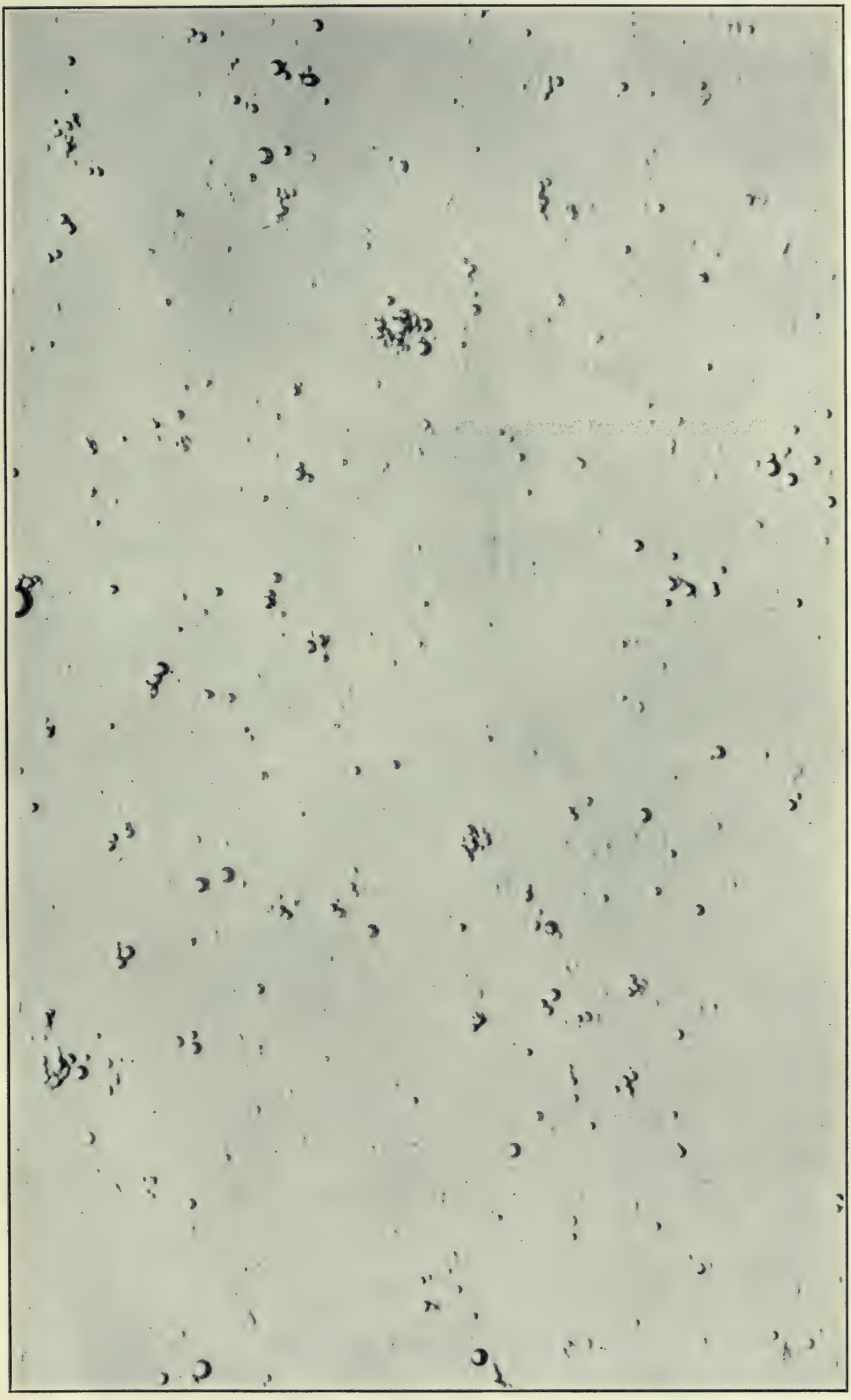
TWENTY PER CENT CREAM PASTEURIZED AT 80° C. AND HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH AT 80° C. × 500



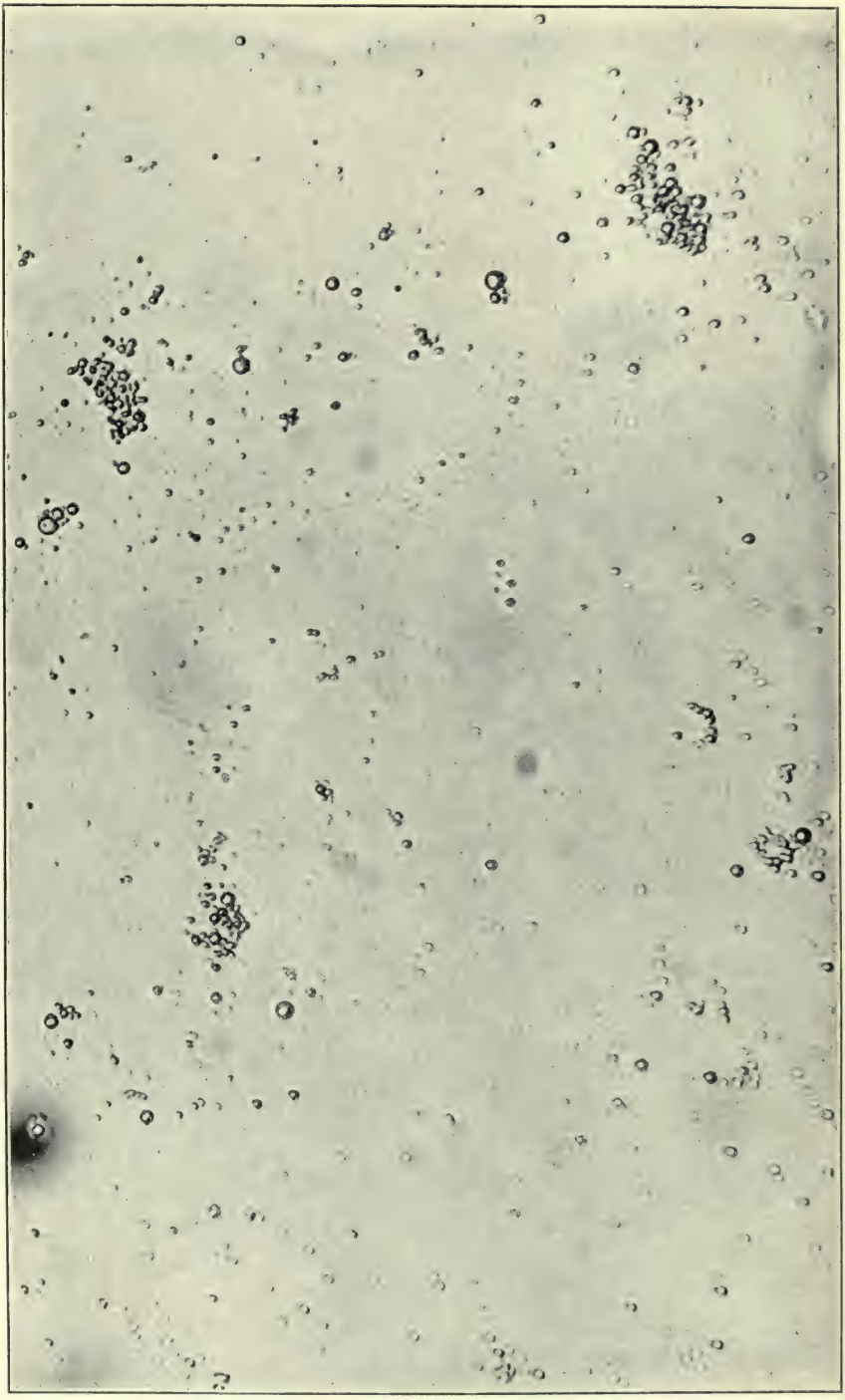
TWENTY PER CENT CREAM PASTEURIZED AT 88° C. AND HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH AT 88° C. × 500



TWENTY PER CENT CREAM HOMOGENIZED AT 2,000 POUNDS PRESSURE PER SQUARE INCH AT 62° C. × 500

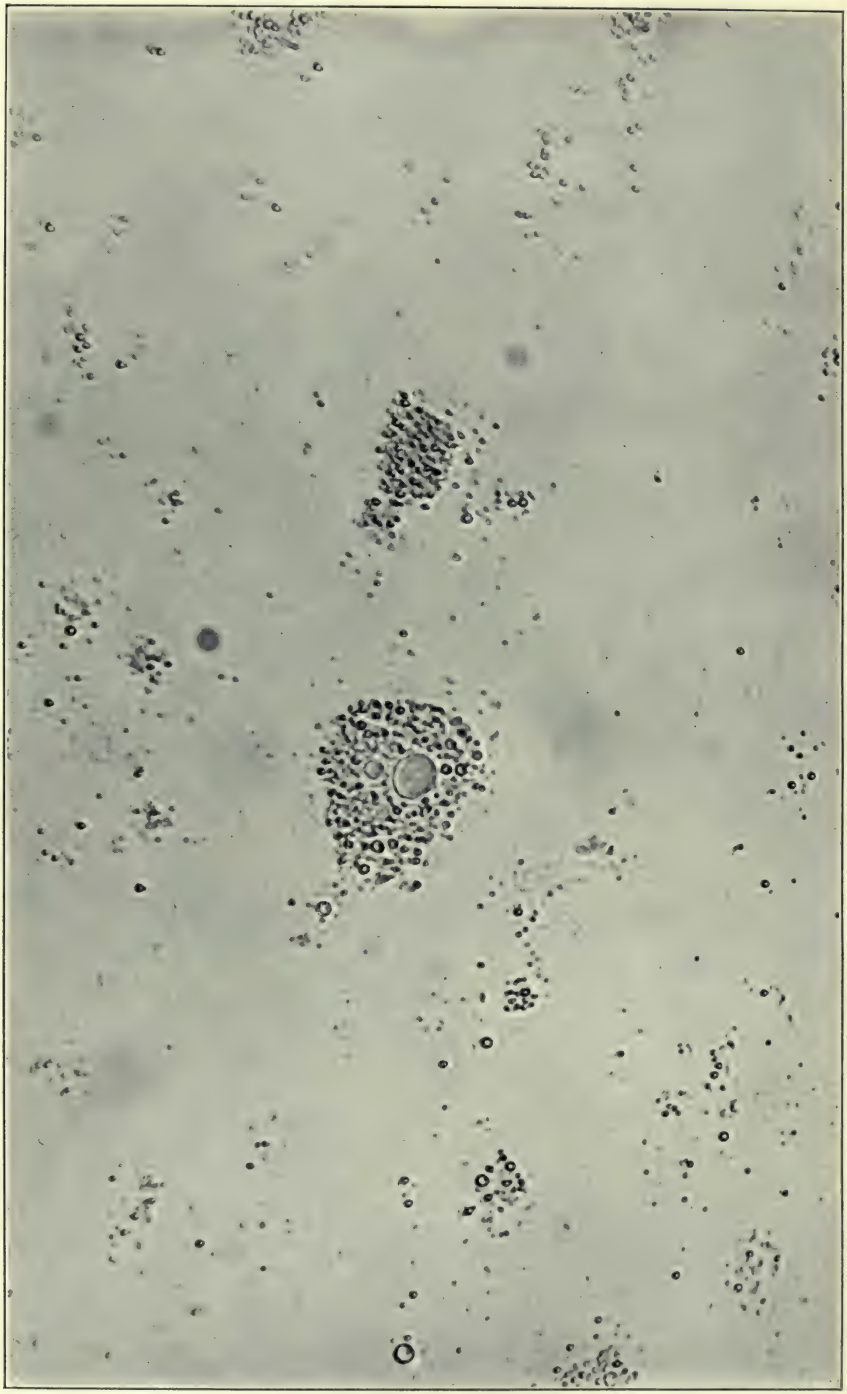


TWENTY PER CENT CREAM HOMOGENIZED AND REHOMOGENIZED AT 2,000 POUNDS PRESSURE PER SQUARE INCH AT 62° C. X 500

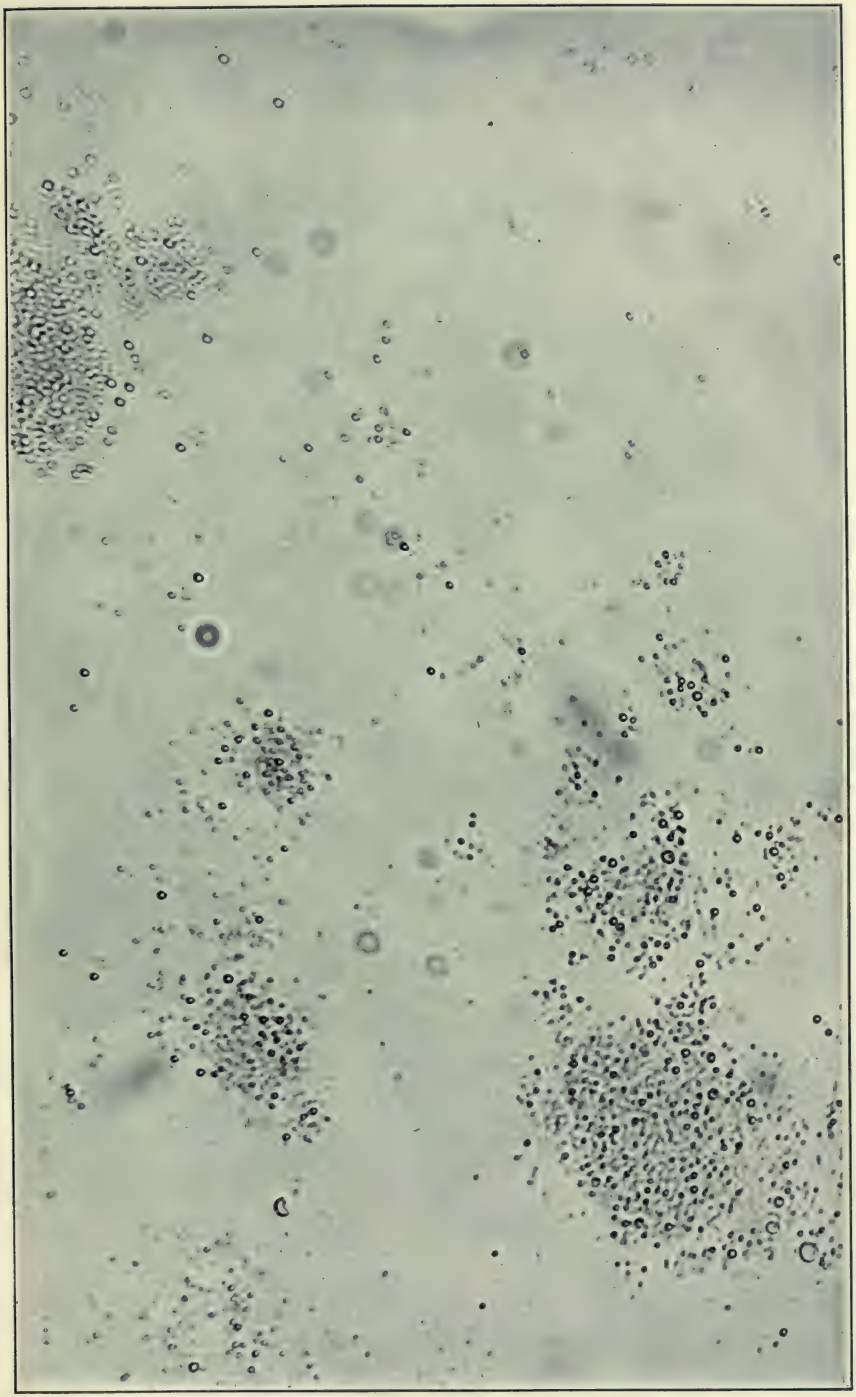


CREAM CONTAINING 20.5 PER CENT BUTTERFAT, AND 2.95 PER CENT SOLIDS NOT FAT, HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH. × 500

CREAM CONTAINING 20.5 PER CENT BUTTERFAT, AND 4.14 PER CENT SOLIDS NOT FAT, HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH. × 500



CREAM CONTAINING 20.5 PER CENT BUTTERFAT, AND 8.80 PER CENT SOLIDS NOT FAT, HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH. × 500



CREAM CONTAINING 20.5 PER CENT BUTTERFAT, AND 11.40 PER CENT SOLIDS NOT FAT, HOMOGENIZED AT 3,000 POUNDS PRESSURE PER SQUARE INCH. × 500

not fat the lower was the relative viscosity. As the percentage of solids not fat was increased the relative viscosity increased. The increase in relative viscosity was gradual until the percentage of solids not fat reached normal, but above the normal percentage of solids not fat the increase was more rapid. This was true especially when

TABLE 10.—*Effect of solids not fat upon the viscosity of cream with a butterfat content of 20.5 per cent*

Solids not fat (per cent)	Relative viscosity at 20° C. of—	
	Cream preheated to 80° C.	Cream preheated to 80° C., and homogenized at 3,000 pounds
2.95	1.25	1.44
4.14	1.30	1.50
6.29	1.39	1.62
8.80	1.58	2.20
11.40	1.84	2.71

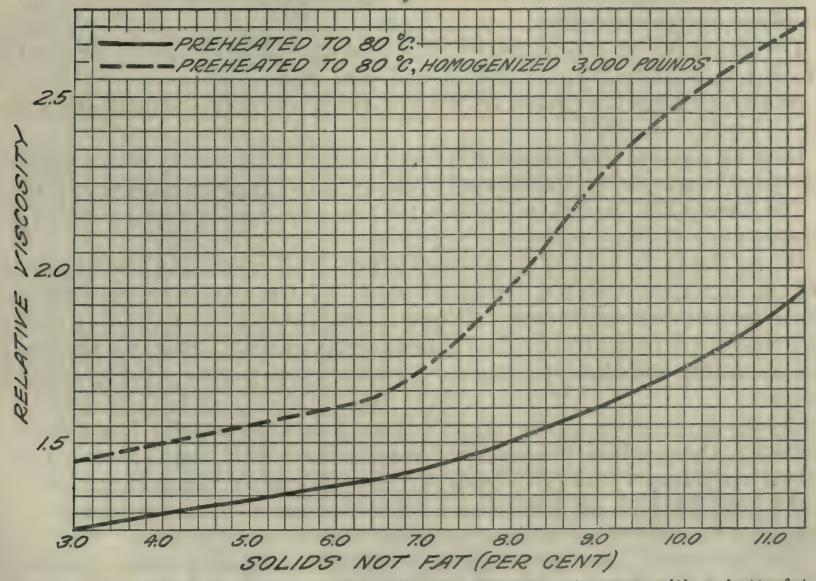


FIGURE 10.—Effect of solids not fat upon the viscosity of cream with a butterfat content of 20.5 per cent

the cream was homogenized. The relative viscosity of the homogenized cream was markedly greater when the percentage of solids not fat was above normal. (Table 10 and fig. 10.)

A microscopic study of the fat globules in cream with the same butterfat content, but with various percentages of solids not fat, showed a variation in the degree of clumping. This variation was noticeable in the homogenized cream particularly. (Pls. 18 to 21, inclusive.)

CONCLUSIONS

There are a number of factors which may affect the viscosity of cream, but those which affect the fat phase are probably the more important, because any factor which affects the clumping of fat globules affects the viscosity of cream.

The viscosity of cream increases as the butterfat content is increased. It also increases as the temperature is lowered.

The viscosity of cream is lowered by pasteurization. The temperature of pasteurization, however, has but little effect upon the viscosity. Pasteurized cream increases in viscosity with age, but not to so great an extent as does raw cream. The greatest increase in viscosity (in the case of either pasteurized or raw cream) takes place during the first 24 hours of aging, and at 48 hours the maximum is approached. When the cream is homogenized there is practically no increase in viscosity, and when cream is both pasteurized and homogenized there is no increase in viscosity with age.

The increase in viscosity with age is accompanied by an increase in the amount of clumping of the fat globules.

The viscosity of gravity-separated cream is higher than that of centrifugally separated cream.

Standardizing cream to a specific butterfat content has practically no effect on its viscosity.

The freezing of cream lowers it viscosity. The viscosity of cream which has been frozen is not restored with age.

Acidity, unless in excess of 0.3 per cent, has but a slight effect on the viscosity of cream.

Raw or pasteurized cream that has been cooled slowly has a higher viscosity than raw or pasteurized cream that has been cooled rapidly.

The lower the separating temperature, the higher the viscosity of cream.

When the milk is held in storage before it is separated the viscosity of the cream is affected by the length of time in storage and the temperature during storage. When storage was at 4° C. the viscosity was increased more than when storage was at 18°. Storing the milk for 12 hours resulted in higher viscosity than storing for only 3 hours.

Cream from milk pasteurized before being separated has a lower viscosity than when the cream is separated and then pasteurized, unless the pasteurized milk is cooled slowly before being separated.

Homogenization of cream increases its viscosity. The increase in viscosity is in direct relation to the homogenizing pressure.

The increase in viscosity due to homogenizing at a given pressure depends upon the temperature at which the cream is homogenized.

Rehomogenization of cream lowers its viscosity.

The viscosity of cream increases as the percentage of solids not fat increases. This is true especially with homogenized cream.

LITERATURE CITED

(1) ACHARD, G., and STASSANO, H.
1925. QUELQUES CONSTANTES PHYSICO-CHEMIQUES DU LAIT CU ET DU LAIT PASTEURIZE SELON DIFFERENTS PROCEDES. Compt. Rend. Soc. Biol. [Paris] 93: 708–710.

(2) BABCOCK, S. M.
1897. THE CONSTITUTION OF MILK WITH ESPECIAL REFERENCE TO CHEESE PRODUCTION. Wis. Agr. Expt. Sta. Bul. 61, 21 p., illus.

(3) BABCOCK, S. M., and RUSSELL, H. L.
1896. CONDITIONS AFFECTING THE CONSISTENCY OF MILK. Wis. Agr. Expt. Sta. Ann. Rpt. 13: 73–80, illus.
(4) ——— and RUSSELL, H. L.
1896. ON THE RESTORATION OF THE CONSISTENCY OF PASTEURIZED MILK AND CREAM. Wis. Agr. Expt. Sta. Ann. Rpt. 13: 81–94, illus.
(5) BATEMAN, G. M., and SHARP, P. F.
1928. A STUDY OF THE APPARENT VISCOSITY OF MILK AS INFLUENCED BY SOME PHYSICAL FACTORS. Jour. Agr. Research 36: 647–674, illus.
(6) BURGWALD, L. H.
1923. SOME FACTORS WHICH INFLUENCE THE FEATHERING OF CREAM IN COFFEE. Jour. Agr. Research 26: 541–546.
(7) CURTISS, C. F.
1927. DAIRY. Iowa Agr. Expt. Sta. Rpt. 1927: 31–33.
(8) DAHLBERG, A. C., and HENING, J. C.
1925. VISCOSITY, SURFACE TENSION, AND WHIPPING PROPERTIES OF MILK AND CREAM. N. Y. State Agr. Expt. Sta. Tech. Bul. 113, 42 p., illus.
(9) DAHLE, C. D., and MARTIN, W. H.
1925. THE EFFECT OF METHODS OF HOMOGENIZATION ON THE QUALITY OF ICE CREAM. Penn. Agr. Expt. Sta. Bul. 196 (Ann. Rpt. 38): 23–25.
(10) DAM, W. VAN, and SIRKS, H. A.
1922. ONDERZOEKINGEN OVER DE OPROOMING VOLGENS HET FRIESCHE SYSTEEM. (UEBER DIE AUFRAHMUNG NACH DEN FRIESISCHEN SYSTEM.) Dept. Binnenland. Zaken en Landb. [Netherlands], Verslag. Landbouwk. Onderzoek. Rijkslandbouwproefsta. 26: [106]–191, illus. [In Dutch. Summary in German, p. 184–186.]
(11) DOAN, F. J.
1927. "VISCOLIZED" MILK AND ITS DETECTION. Jour. Dairy Sci. 10: 501–512, illus.
(12) ———.
1929. SOME FACTORS AFFECTING THE FAT CLUMPING PRODUCED IN MILK AND CREAM MIXTURES WHEN HOMOGENIZED. Jour. Dairy Sci. 12: 211–230.
(13) EVENSON, A. L., and FERRIS, L. W.
1924. THE VISCOSITY OF NATURAL AND REMADE MILK. Jour. Dairy Sci. 7: 177–188, illus.
(14) MORTENSEN, M.
1918. FACTORS WHICH INFLUENCE THE YIELD AND CONSISTENCY OF ICE CREAM. Iowa Agr. Expt. Sta. Bul. 180, pp. [258]–283, illus.
(15) PYNE, G. T., and LYONS, J.
1928. SOME FACTORS INFLUENCING VISCOSITY IN CREAM. World's Dairy Cong. Rpt. Proc. 1928: 184–188.
(16) REID, W. H. E., and MOSELEY, W. K.
1926. THE EFFECT OF PROCESSING ON THE DISPERSION OF FAT IN AN ICE CREAM MIXTURE. Missouri Agr. Expt. Sta. Research Bul. 91, 25 p., illus.
(17) SHERWOOD, F. F., and SMALLFIELD, H. L.
1926. FACTORS INFLUENCING THE VISCOSITY OF CREAM AND ICE CREAM. Jour. Dairy Sci. 9: 68–77.
(18) STEINER, R.
1901. BEITRÄGE ZUR KENNTNIS DES EINFLUSSES DER PASTEURISIERUNG AUF DIE BESCHAFFENHEIT DER MILCH UND AUF DEN BUTTERUNGSPROZESS. Milch Ztg. 30: 401–403.
(19) WEBB, B. H., and HOLM, G. E.
1928. THE HEAT STABILITY AND FEATHERING OF SWEET CREAM, AS AFFECTED BY DIFFERENT HOMOGENIZATION PRESSURES AND DIFFERENT TEMPERATURES OF FOREWARMING. Jour. Dairy Sci. 11: 253–257, illus.
(20) WHITAKER, R., SHERMAN, J. M., and SHARP, P. F.
1927. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SKIMMILK. Jour. Dairy Sci. 10: [361]–371, illus.
(21) WHITTAKER, H. A., ARCHIBALD, R. W., SHERE L., and CLEMENT, C. E.
1925. EFFECT OF VARIOUS FACTORS ON THE CREAMING ABILITY OF MARKET MILK. U. S. Dept. Agr. Bul. 1344, 24 p., illus.
(22) WOLL, F. W.
1896. THE EFFECT OF PASTEURIZATION AND STERILIZATION ON THE VISCOSITY AND FAT GLOBULES OF MILK AND CREAM. Wis. Agr. Expt. Sta. Ann. Rpt. (1895) 12: 164–173.

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TECHNICAL BULLETIN No. 250 AUGUST, 1931

TIMBER GROWING *and* LOGGING PRACTICE *in the* SOUTHERN APPALACHIAN REGION

BY

E. H. FROTHINGHAM

Director, Appalachian Forest Experiment Station
Forest Service

INTRODUCTION BY

R. Y. STUART

Forester, Forest Service

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CONTENTS

	Page
Introduction	1
The timber-supply problem in the southern Appalachians	5
Distribution and condition of timberland	6
Timber growing for industrial needs	7
Development of the lumber industry	8
Utilization of small timber	10
Need for continuous production	14
Timber growing and the problem of land use	17
Factors that affect continuous timber production	20
Composition of the forest	21
Mountain forests	21
Plateau and valley forests	22
Relative value of the species	25
The yield of the forest	30
Yield of the old-growth forest	30
Yield of repeatedly culled forest	31
Yield of second growth	35
Forest-fire damage	37
Establishment and early development of stands	40
On unburned cut-over lands	40
After fires on cut-over lands	41
Seedling and sprout reproduction	43
Effect of competition in young stands	45
Forest-insect damage	47
Insects affecting living trees	47
Insects affecting forest products	49
The chestnut blight	49
Economy in reserving small trees for growth	54
Measures necessary to keep forest lands productive	57
Fire prevention	57
Causes of fires	57
Need for cooperation	58
General measures	59
Special measures	63
Logging practice	66
Measures necessary to keep forest lands productive—Continued.	
Logging practice—Continued.	
Improvement of poor stand conditions	66
Selection of seed trees	69
Management of forests to produce full timber crops	70
Full-crop management for large timber tracts below the spruce zone	71
Methods of cutting	71
Improvement cutting and girdling	73
Weeding	74
Thinning	75
Slash disposal	75
Spruce-forest management for full crops	75
Management of farm woods	78
Old-growth stands	79
Second-growth stands	80
Species to be favored	80
Control of grazing	81
Cooperative marketing	81
Summary of recommendations for handling forest lands	82
To keep forest lands productive	82
Fire prevention	82
Insect control	83
Logging practice	84
To produce full timber crops	85
Large timber tracts	85
Spruce forest	85
Farm woods	85
Public action needed for better development of timberlands	86
Appendix	87
Sources of technical advice and service for private forest management	87
Common and scientific names of trees referred to in text	87
Literature cited	89

INTRODUCTION

Forestry in the United States is no longer merely a theory or a subject for discussion; it has got down to concrete things in the woods. Nor is the growing of timber confined to public lands; it

is slowly making headway on land in private ownership. It is becoming a form of land management, developed through practical measures for protecting forest growth from fire and other destructive agencies, for logging woodlands so as to carry over or reproduce a crop of timber, and for planting forest trees on cut-over areas. The value of timber, with other economic considerations, is causing landowners more and more widely to study the possibility of profitable reforestation. These developments have created a general demand for information on the timber-growing methods adapted to the various types of forest growth in the United States and what these methods will cost.

Timber culture, like the growing of farm crops, is necessarily governed in any country by the soil and climate, by the requirements of native forest trees, and by local economic circumstances. Lessons may be drawn from the experience of other countries, as the United States has drawn upon the forestry of Europe. But profitable methods of growing timber, particularly under the wide range of forest types and economic conditions in the United States, can be worked out only from our own experience and investigation, region by region. Hence, to meet the need for information on practical ways and means of growing timber profitably in the various parts of the United States, it is important that the results of our own experiences and investigation to date be brought together and set forth in the clearest possible way.

This the Forest Service has attempted to do in a series of publications dealing with 12 of the principal forest regions of the United States. The information presented has been gathered from many different sources, including the experience of landowners who have engaged in reforestation. An effort has been made to bring together the gist of what has thus far been learned about the growing of timber in the United States; and the results have been verified as far as possible by consultation with the forest industries, State foresters, and forest schools. This bulletin thus undertakes to set forth what are believed to be the soundest methods of reforestation as yet developed in our common experience and study in the Appalachian region.

Necessarily, no finality is claimed for the measures proposed. Timber growing in every country has come about through a gradual evolution in industrial methods and the use of land. All too little is yet known of the best methods of growing timber in the Appalachian region. As time goes on, research and practical experience will add greatly to the success and certainty of the practice in our woods, just as, through experience and study, American agriculture has steadily become more highly developed and manufacturing processes have been perfected. But enough is now known about growing timber in the Appalachian region to go right ahead. Believing that the forest-land owners of this region are ready to engage in timber growing, the Forest Service has endeavored to place before them in concise terms the best suggestions and guides which its experience to date affords.

In this bulletin the measures proposed have been arranged in two general groups. The first includes the first steps, or the least that must be done under the local physical conditions, to prevent timber-

bearing land from becoming unproductive. These measures, in which the prevention of fire is of outstanding importance, represent broadly the lowest cost that must be incurred to keep forest lands reasonably productive. They have been worked out primarily from the standpoint of the landowner who may not be ready to engage in real timber culture but who wishes to prevent cut-over tracts unsuitable for any purpose except timber growing from becoming a liability on his hands. The Forest Service believes that these first steps, or minimum measures, should be speedily applied to all of the forest lands in the Appalachian region and that public policy should encourage their universal application in such ways as protection from fire and the adjustment of forest taxation to the business of timber growing.

The second group of measures, proposed as a system of management to produce full timber crops, constitutes what may be called desirable forestry practice as far as our knowledge and experience to date enable us to determine it. These measures are designed to grow reasonably complete crops of the more valuable timber trees, making full use of the productive capacity of the land. Such recommendations are addressed primarily to the landowner who wishes to use his property up to its full earning power for timber culture. It is impossible to frame any general set of measures of this character that are adapted to the individual needs of particular holdings or industrial establishments. This is true particularly of forest regions like the southern Appalachians, which include a great variety of local situations, both in types of forest growth and in economic circumstances. Hence, in presenting this group of suggested measures, the Forest Service has attempted only to outline the more general and fundamental things, with illustrative methods of forest practice. The details of intensive forestry, like the details of intensive agriculture or engineering, call for an expert survey to work out the plans and methods best adapted to a particular tract of land or a particular business. One of the most important features of planning for the management of a forest property or a supply of raw material for a forest industry is to devise not simply logging methods that will reproduce crops of timber but a scheme of operation that will afford a continuous yield of the products desired. Thus only may sustained earnings be realized or a sustained supply of raw material made available.

It is not always practicable to draw a hard and fast line between the first steps that will maintain some degree of productiveness on forest land and the more intensive measures that will bring the quantity and quality of wood produced up more nearly to an ideal management. The author has not attempted, therefore, to deal with the two general types of forest practice as separate and distinct but has rather endeavored to present a common-sense and practical résumé of the various steps in timber growing in the form that will be most helpful to men to whom timber growing is a concrete business and logging problem. At the same time it is hoped that the bulletin will have value for the everyday reader who is interested in forestry as an important phase of land use in the United States and in the public policies designed to bring forestry about.

It is impossible for a publication necessarily dealing in broad terms with the conditions existing over a large region to attempt any

brass-tack conclusions on the cost and returns of timber growing. The approximate cost of the measures advocated is indicated as far as practicable, with the extent to which they may be of benefit to logging operations, but with no attempt to segregate the items chargeable to harvesting one crop of timber from those which should be regarded as invested in a following crop. Conservative estimates of the future yields of timber that may be expected under the practices recommended are given where facts appear to warrant them; but no forecasts of the profits to be derived from commercial reforestation are attempted. The financial aspects of forestry can not be dealt with in general terms. Here again expert advice must deal with the land and business problems of the individual forest owner or manufacturer.

As a broad conclusion, the Forest Service has tremendous faith in the commercial promise of timber growing to American landowners. The law of supply and demand is working steadily to create timber values which will pay fair returns on forestry as a business. The economic history of other countries which have passed through a cycle of virgin-forest depletion similar to that which the United States is now traversing points to the same conclusion. The time is fast approaching when forestry, and forestry alone, will supply the enormous quantities of wood demanded by American markets. The fundamental laws of business tend in the nature of things to enable the markets for forest products to be supplied at a profit to the grower of timber. The returns already being obtained from this form of land employment at many points in the eastern United States show plainly enough that this relationship between the value of timber and the cost of producing it is already coming into being.

To the men who own forest-producing land in the United States or who are engaged in industries which require timber as raw material, forestry now offers a commercial opportunity. Satisfactory returns from forestry can not be promised in sweeping terms any more than returns from the manufacture of lumber or paper. But the opportunity for a profitable employment of capital and business talent in the growing of timber merits the same consideration and the same expert guidance as industrial opportunities in the conversion of timber. This applies with special force to commercial institutions which have made large capital investments in manufacturing plants and distributing organizations, dependent for their maintenance upon a future supply of forest-grown material. It applies also to owners of land, in large tracts or farm woodlands, the earning capacity of which lies mainly in the growing of trees, and which, without tree growth, will become either a doubtful asset or an outright liability.

The Forest Service earnestly asks the forest-land owners of the Appalachian region to determine for themselves, with the same care with which they would approach any other business problem, whether timber growing does not offer a commercial opportunity which should be grasped. It commends this bulletin to them, not as a complete or authoritative scheme that can forthwith be followed with profit in their own woods but as a starting point in utilizing the opportunities that forestry may offer.

R. Y. Stuart.

THE TIMBER-SUPPLY PROBLEM IN THE SOUTHERN APPALACHIANS

The southern Appalachian region (fig. 1) consists of two long and rugged mountain systems surrounded and penetrated by well-populated plateaus and valleys. The western system of mountains comprises the Alleghenies and the Cumberlands; the eastern—or the southern Appalachians proper—takes in the Blue Ridge and Smoky Ranges and cross ranges. The mountains are mostly forest land (pls. 1 and 2) and are adapted by climate and soil for the

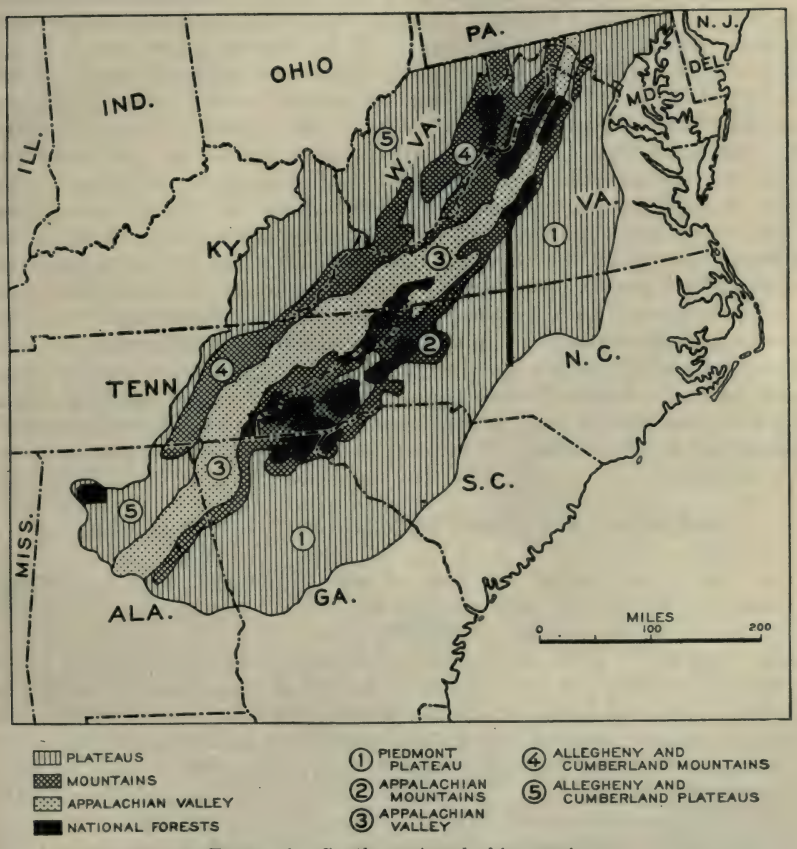


FIGURE 1.—Southern Appalachian region

growth of commercial forest products in variety unequaled outside of the Tropics. Heavy forests once covered these slopes, and these while they remained made the southern Appalachians a timber-producing center which grew in importance as industrial demands for wood products increased in the surrounding region. From the mountains there are many outlets by rail and motor road to near-by industrial centers in the great Appalachian Valley, which separates the two main ranges, and to those on the Allegheny, Cumberland, and piedmont plateaus, which skirt the mountains on the west, south, and east. Railroads lead in all directions through the region to

large markets and shipping points outside. The plateaus and valleys themselves are dotted with farm woods, isolated, or contiguous in strips or blocks, which are even more accessible to markets than the mountain timberlands.

After many years of logging the original timber supply of this region is nearing its end. Its replacement has been hindered by repeated cullings which removed most of the usable timber and left the poorest. Forest fires, insects, and the chestnut blight have also contributed to reducing the growth rate on otherwise productive forest soils. Thus, while there remain in the mountains a number of timber tracts large enough to supply double-band sawmills for one or two decades, as well as many smaller second-growth stands of much promise, the greater part of the forests have not only lost in actual value of standing timber but have suffered more or less severely in their capacity to produce valuable new growth. To maintain the large supplies of lumber and other forest products which have hitherto been available within the region for its industrial needs, the productive value of the timberlands must be preserved where it still exists and should be restored on the larger areas where it has been lost or reduced. The timber-supply problem of the southern Appalachian region is therefore mainly one of converting depleted and poorly growing forests into stands which will be both rapidly and continuously productive. It is the purpose of this bulletin to describe briefly the southern Appalachian forests, the demands upon them, the factors that affect their reproduction, growth, and value, and the kind of treatment which appears necessary to maintain the productivity of the forests, or, better, to insure perpetual timber yields of the largest amount and highest value that the soil will sustain.

DISTRIBUTION AND CONDITION OF TIMBERLAND

For the entire region the area of actual and potential timberland amounts to about 60,771,000 acres, or 59 per cent of the total land area. Of this, more than 21,000,000 acres are in the mountains, but nearly 40,000,000 acres are on the plateaus. Extensive timber tracts however, are found only in the mountains; on the plateaus the forest consists chiefly of farm woods of 50 acres or less. Farm woods also make up 30 per cent of the total forest area in the mountains, but here they are larger and generally adjoin one another and the more extensive timber tracts. Thus, the forests of the mountains and those of the plateaus and valleys differ both in continuity and size of separately owned tracts. Viewed as a source of perpetual supply, the farm woods present conditions quite different from those of the more concentrated timberlands in the mountains.

The eight national forests in the region on June 30, 1929, covered an aggregate area of 1,988,563 acres, or about 3 per cent of the total area of actual or potential forest. This area is being increased under the present Federal program for national forests in the southern Appalachians. National parks, for which land is now being purchased, are expected to cover 755,000 acres in North Carolina, Tennessee, and Virginia. According to recent statistics (*72*),[1] State

[1] Italic numbers in parentheses refer to Literature Cited, p. 89.

forests and parks occupy 15,393 acres in West Virginia, 3,835 acres in Maryland, 3,624 acres in Kentucky, 1,724 acres in North Carolina, and 588 acres in Virginia, or a total of 25,164 acres. Municipal and county forests and parks, largely for the protection of water supplies, aggregate 61,727 acres in North Carolina, Maryland, and Virginia. The total area now or soon to be under public administration as forests or park in the southern Appalachian States is therefore about 2,830,000 acres, or less than 5 per cent of the total forest area. Ninety-five per cent of the area suitable for timber growing in the southern Appalachian region is privately owned.

The area of timberland in public ownership is too small to make very much difference in the production of the region as a whole, no matter how well protected and managed the public forest may be. The forest problem is therefore chiefly one of privately owned tracts, large and small. In the mountains the large size of many of the holdings and the general continuity of forest land favor large-scale management. In the plateau and valley regions, accessibility and the chance of occupying labor during off periods offer different but equally advantageous possibilities for small-scale productive treatment. It is evident that if the southern Appalachian forests are to continue as a self-sustaining supply for the industrial and domestic needs of the region, this must be brought about through the intelligent practice of forestry, and that largely by the private owners.

In its present condition the forest varies from virgin timber stands to heavily cut-over land, from unburned to badly fire-damaged stands, and from freshly cut, newly reproducing areas to dense stands of second growth. Virgin stands remain in only a few places, mostly in the mountains. Their aggregate area has been roughly estimated at less than 300,000 acres in West Virginia, 220,000 acres in Virginia, and between 1,000,000 and 1,500,000 acres in the rest of the region. Even these estimates include a considerable area that has been lightly culled in the past. The remainder of the mountain timberland has been culled or cut over more or less heavily. The cuttings have generally been partial, removing the products that could be profitably taken at the time and thereby increasing the proportion of unmerchantable timber in the stand. Many tracts have been worked over repeatedly for different products at intervals of a few years. On the other hand, clear cutting was at one time extensively practiced in Maryland, Virginia, West Virginia, and a few places in the States farther south, to supply charcoal wood for the many iron furnaces that once were operated. On the lands thus cut over a dense, even-aged second growth has appeared, consisting principally of mixed hardwoods. Most of the second-growth stands that remain on the "coaled lands" are now from 30 to 80 or more years old.

The varying conditions that must be dealt with in bringing cut-over areas into continuous production will be discussed at a later point in the bulletin.

TIMBER GROWING FOR INDUSTRIAL NEEDS

As a source of supply for local industries and for shipment to outside markets the southern Appalachian forests have played an important part in the economic development of the region. The kinds

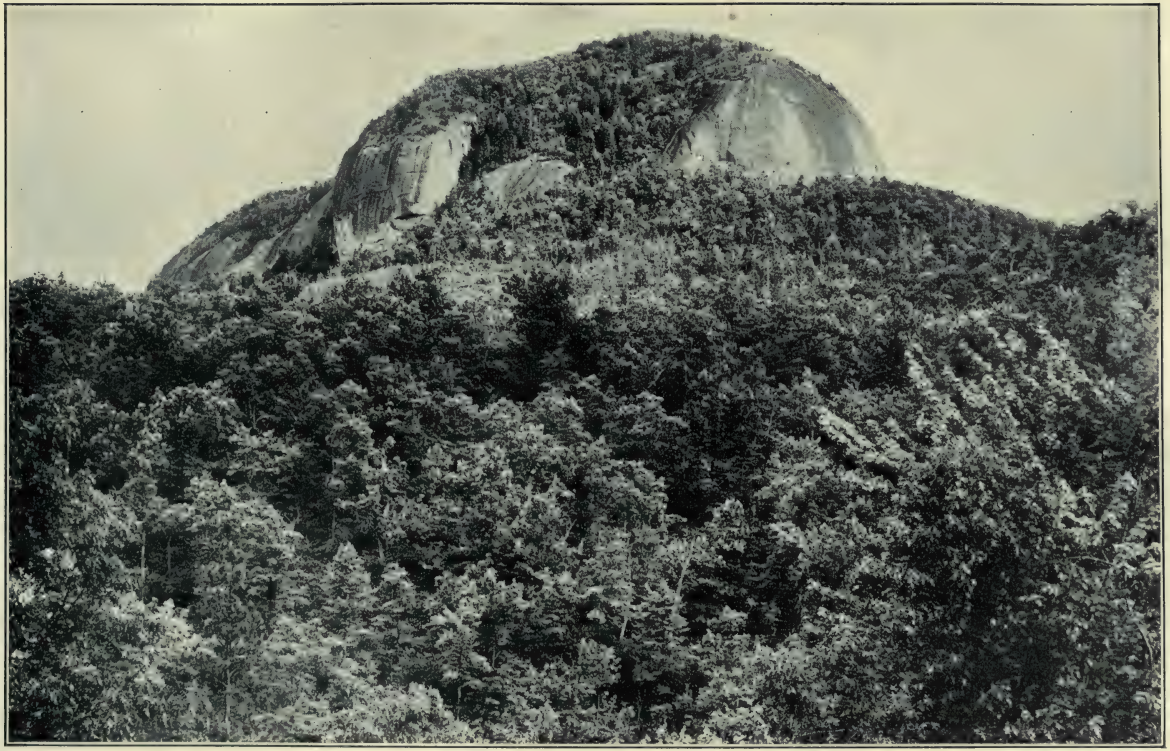
and quantities of materials removed and the methods employed explain in some measure the present condition of the forests.

DEVELOPMENT OF THE LUMBER INDUSTRY

Extensive lumbering began in the southern Appalachians later than in other eastern forest regions. It grew up in response to an increasing demand for the hardwood products which could be obtained in great variety and high quality in these virgin forests. In the early days cutting was confined to the forests immediately adjacent to the main rivers and their branches. When the development of the railroad systems through the territory made accessible the timberlands away from the rivers, and at the same time brought an active demand for crossties, timbers, and poles, logging gradually became important along the railroads. From that time on the timber industry in a new locality began with the building of logging railroads, or of wagon roads into the timber from a railroad shipping point. Band-saw mills cutting from 25,000 to over 100,000 board feet of lumber per day were erected within reach of bodies of timber large enough to sustain the mills through the period necessary to amortize the investment.

The kind and the quality of products that could be profitably exploited have undergone a marked change during this comparatively short period. Forty-five years ago only the walnut, cherry, and the finest of the yellow poplar, white pine, basswood, cucumber magnolia, and white oak were worth taking. Commonly only a light culling of the forest was made. Very few trees were logged that were under 30 inches on the stump, and no logs were taken at the mills that were less than 20 inches in diameter at the small end. Ten years later the usual cutting limit was 24 inches on the stump, and logs 18 inches in diameter could be handled in the mills; as a rule, only perfectly clear logs containing at least 350 board feet were accepted. By about 1900 the average cutting limit in the woods had dropped to 21 inches on the stump and the average small-end diameter of logs at the mill to 17 inches. By 1905, oak and chestnut trees 15 inches on the stump and poplar 14 inches or even less were being taken, and logs that contained 100 board feet were handled at the mills. Within the last few years, in seasons of active movement of lumber, trees 9 to 10 inches on the stump have been cut for lumber by large mills, while portable mills have cut to even smaller diameters, in spite of the fact that trees of such small diameters, as will be pointed out later, can rarely, if ever, be handled except at a loss—a fact frequently overlooked, especially by operators of small mills.

Meanwhile, markets have developed for species which had no value in the early days of logging. Black oak, scarlet oak, chestnut oak, and chestnut, which were passed by entirely in most of the first cuttings, are now logged extensively. Sugar maple has acquired value for flooring, while black gum, hemlock, birch, beech, and many other species that formerly were not considered, now have value enough to warrant cutting. At the same time, the grades of logs accepted by sawmills have dropped. About 35 or 40 years ago little was cut that would not saw out in lumber grading 50 per cent firsts and seconds. Probably 40 or 50 per cent of the rougher timber that



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THE SOUTHERN APPALACHIAN HARDWOOD FOREST

This stand, near Lookingglass Rock in Pisgah National Forest, N. C., was culled in 1917 to diameters of 14 to 16 inches. By well-directed partial cuttings the yield of such stands can be perpetuated and their beauty preserved.

Asheville Photo Service O-689

A SPRUCE-FIR FOREST IN THE BLACK MOUNTAINS, N. C.

A narrow strip (mostly of fir) along the crest is all that remains of the forest that once covered the slopes. Most of the remaining stand is within the Mount Mitchell State Park and the Pisgah National Forest. The burned slopes have been planted with spruce and other conifers by the Federal and State forest services.

was waste in 1890 is now utilized, and the average grade of lumber has been lowered at least 30 or 40 per cent since then. In 1890, at Chattanooga, Tenn., poplar logs ran 60 to 70 per cent No. 1; 15 years later they ran about 15 per cent No. 1. The trend is toward the use of poorer species or poorer grades of the better species, for the purposes for which only high-grade materials were acceptable a few years ago.

The changes in market conditions resulted in constantly heavier cullings of the forest and less timber left standing. Until comparatively recent years, however, enough was left to justify the reworking of areas already cut over, especially as the demands for pulpwood and chestnut tanning-extract wood made possible the use of small sizes and previously worthless species. As a consequence a large part of the timberlands has been cut over again and again, sometimes six or eight times.

The increase in the variety of merchantable wood products led to more concentrated logging and to closer utilization at the manufacturing plants. For skidding and loading logs, steam apparatus partially replaced the horses, mules, and oxen once exclusively used for this work. Animals are still quite widely used, but on the few remaining large operations logging is now mainly by machine ground-skidding or overhead cable to a logging railroad. The use of animals is frequently combined with machine ground-skidding to increase range of operation. Some operators are employing gasoline tractors and trucks for hauling both logs and lumber. At the large mills, also, efficient utilization is being accomplished by means of gang saws, edgers, trimmers, and equipment for manufacturing otherwise waste material into lath, flooring, and other incidental products. There is a certain amount of trade in low-grade lumber and in trimmings and edgings that are shipped from the sawmills to furniture factories or plants equipped for the manufacture of a great variety of novelties, trimmings, moldings, etc., from small-dimension material. Some of the pulp mills and tanning-extract plants in the region have obtained a part of their supply from sawmills in the form of slabs and other waste material. The manufacture of veneer has established a demand for especially good logs, largely of yellow poplar.

A later chapter in logging history is concerned with the portable sawmill, which has become an important factor in the problem of continuous timber production. Large numbers of these mills with a daily capacity of 6,000 to 8,000 board feet have come into use, commonly in stands already culled or cut over, taking what remains merchantable of the saw log and tie timber left from previous operations. Much of the output is poorly manufactured and poorly graded and commands lower prices than would be obtainable under more efficient operation.

With no large investment ordinarily tied up in timber or timberland ownership, portable-mill operators, as a rule, have even less interest in the future of the lands cut over than do the large operators. In seasons of active demand set-ups are justified for tracts of 50,000 or 100,000 board feet, and the investment can be entirely liquidated in one or two months' operation. In periods of small demand, portable mills can shut down without difficulty. Consequently the number

of portable mills in operation fluctuates constantly and rapidly. The unregulated cutting now practiced by most portable mills is a threat to continuous timber production. The desirable trees are cut, the undesirable left standing, and a serious drain upon the growing stock is thus imposed which can not be so easily checked and corrected as on large operations. Employed with a view to the betterment of the stand, however, the portable mill can probably be more easily transformed into a constructive agent than can the large stationary mill with its heavy continuous demand for logs.

The lumber cut for the entire region was about at the maximum in 1909, when the output in hardwood lumber alone was about 4,000,000,000 board feet (*71*). As nearly as can be judged from available statistics (*72*), the present annual cut in the parts of the States included in the southern Appalachian region is approximately 2,250,000,000 board feet.

UTILIZATION OF SMALL TIMBER

Large quantities of wood in the form of railroad ties, pulpwood, tanning-extract wood and bark, mining timbers, cooperage stock, firewood, poles, posts, and many other products are cut annually in the region. Such exploitation may contribute either to the improvement or the deterioration of the forest. Most of these products are obtainable from trees of less than saw-log size. The removal of such trees when diseased, defective, poorly formed, or of inferior species, is usually beneficial, giving space for better growth in the remaining stand; but the heavy cutting for these purposes of young, thrifty timber during the period of its rapid growth into wood of high quality means a loss in future production. At the same time, the prospect of increasing need for small products by industrial plants in the region makes it necessary to provide for a continuous supply.

RAILROAD TIES

Annual replacements by the railroads entirely within the southern Appalachian region probably require more than 2,000,000 ties, or from 65,000,000 to 70,000,000 board feet of timber. The greater number of these are of oak, particularly the white oaks; but since the introduction of preservative treatment, ties of almost all species that reach tie size have been accepted at various points in the region.

To-day a large proportion of the ties are sawed, whereas 20 years ago the bulk of the ties were hewed (*74*). In hewing ties the cutter prefers straight-grained, clear trees 11 to 17 inches d. b. h.,[2] rarely as small as 9 inches. Such trees are commonly the ones that contain the greatest promise for lumber or veneer. As a rule tie hewers get only a single tie from each tie length cut out of trees less than 15 inches d. b. h., and the wood slabbed off is wasted. In the sawmill much of this material can be saved as clear side lumber or used for the manufacture of small-dimension products. Where sawed ties are as readily accepted as hewed ties and where logging is not difficult, sawing will almost invariably prove cheaper and more profitable than hewing. An exception is the small farm

[2] D. b. h.=diameter at breast height, or 4.5 feet from the ground.

woodland where tie cutting may often prove the most advantageous means of removing and utilizing a few trees from time to time for the improvement of the stand.

In the dense, even-aged second growth that has grown up on lands clear cut for charcoal, stands 50 or 60 years old will yield, on an average, 60 ties per acre.[3] The yield of the more open stands on ridge land may be 50 or even as low as 25 ties per acre at the same age, while in coves it may be 80 or more.

PULPWOOD

In 1929, 16 pulp mills were operating in the mountain and piedmont region, but since a number of these obtain part of their wood supplies from the coastal plain or other sources, the quantity supplied by the southern Appalachians is hard to estimate. The annual output of the mills that draw upon the mountain and plateau woodlands for much of their supply may be estimated as between 225,000 and 275,000 tons of pulp. Their annual wood consumption from mountain and plateau sources is probably from 400,000 to 500,000 cords

The pines and the softer hardwoods are the principal species used. Virginia and shortleaf pine are extensively manufactured into sulphate pulp for container board and kraft wrapping paper, while yellow poplar, basswood, black gum, red gum, maple, birch, and beech are pulped chiefly by the soda process for book paper. A very small quantity of spruce and hemlock is converted into pulp at a few ground-wood and sulphite mills, but the remaining stand of spruce available for pulp is too insignificant in amount, and the hemlock is generally too scattered to offer promise for any extended use of these species.

Within recent years the manufacture of container board out of spent chestnut chips from tanning-extract plants has made it possible to combine these two industries effectively at several places and to stimulate the salvage of chestnut that would otherwise be wasted. Extended to other fields, such combinations of wood-using industries could be made the means of obtaining closer utilization and of controlling the management of forest lands. One fact that has prevented the rapid development of soda-pulp operations in this region is that the hardwood species suitable for pulp are not closely concentrated but usually occur mixed with oaks and other hardwoods for which no commercially profitable pulping process has yet been discovered. A systematic form of utilization that will give value to all these species together, for pulpwood, lumber, and other forest products, offers a means by which the southern Appalachian forests may profitably be exploited and may be established on a basis of permanent timber production. Such joint operations must of course be conducted over an area sufficiently large so that the combination of industries can be supplied from the current timber growth, without necessitating clear cutting and thus depleting the reservoir of growing stock.

[3] From a study of the tie industry in the southern Appalachians made in 1904 by Raphael Zon.

On the national forests the hardwood species suitable for paper pulp—yellow poplar, basswood, chestnut, maple, birch, beech, buckeye, cucumber, cherry, and others—constitute about 29 per cent, and the suitable softwood species about 31 per cent, of the total stand.

TANNING-EXTRACT PRODUCTS

There are 40 to 50 tanning-extract concerns, tanneries, and large dealers in wood and bark in the southern Appalachian region. Formerly bark, mostly of chestnut, oak, and hemlock, was the only native forest product utilized by the tanneries, but with the introduction, 25 or 30 years ago, of chestnut wood as a source of tanning extract, this species increased rapidly in importance. To-day most of the extract plants depend upon chestnut for a large part of their supply. For several years, however, the market for tanning extract has been dull. Furthermore, the higher tannin content of other materials, chiefly quebracho, which can be imported relatively cheaply from foreign sources, has led to a partial displacement of native materials.

In order of quantities consumed, the greater part of the tanning-extract materials consists of chestnut wood, chestnut oak bark, and hemlock bark. A few plants use the bark of red, scarlet, and white oaks, spruce bark, sumac leaves, and chestnut oak wood. A few others make extract from the bark of black oak, but this product is a dyestuff rather than a tanning agent.

Chestnut-wood operations quite commonly follow logging for saw timber or for chestnut poles. These operations remove the chestnut trees that were too poor or small for logs, as well as portions of trees from which saw logs have been cut, including straight tops and branches to a diameter as small as 3 inches. Where chestnut forms a large proportion of the stand—as it very often does in the mountain hardwood forest—the result of this combined exploitation is to leave very little timber on the area. Were it not for the chestnut blight, which will be discussed at length on a later page, this reduction in growing stock would be regrettable. As it is, it becomes a means of salvaging material that would otherwise be wasted and of leaving the ground more free for the development of other species.

The bark is even more strictly a by-product of logging operations. Formerly timber was often cut for the bark alone, the stripped chestnut oak or hemlock trunks being left in the woods to rot. Very little waste of this kind is now noted. On the contrary, considerable bark is wasted on unpeeled logs sawed for lumber. This is ordinarily the case when trees are cut at other seasons than in the spring when bark can be easily peeled. Bark-peeling operations proceed either in the spring in advance of logging or after the unpeeled logs are delivered at the mill yard.

The combination of paper-board and wrapping-paper manufacture with extraction plants, as a means of more economical operation and better utilization, has already been mentioned.

MINE TIMBERS

According to statistics of the Bureau of the Census and the Forest Service (*72*), the mines of the southern Appalachian region

consumed in 1923 a total of 35,794,540 cubic feet of round timber and 81,870,000 board feet of sawed timber. About half of this was used in West Virginia.

Of the various timbers used by the mines the greatest demand upon the forest is for props and tram ties. Mine props vary in length from 3 to 12 feet and may be as small as 4 inches in diameter at the small end. Tram ties are 5 feet long and have a 4 or 5 inch face. These small sizes are obtainable from young second-growth timber. On some of the mining properties such stands are cut over as frequently as small quantities of this material can be obtained, thus greatly reducing the yield that would result from a few more years of growth. This overcutting at short intervals reduces the stand to a deteriorated sprout forest.

Mine timbers, like pulpwood and railroad ties, provide a means of utilizing the unmerchantable trees left in logging saw timber. At places in or near the coal-mining regions of West Virginia and eastern Kentucky many large trees, chiefly beech, were left on cut-over areas, where they have become a serious detriment to the successful restocking of the forest. Where areas in this condition are sufficiently near coal mines their reworking for mine timbers will relieve the drain on other sources of supply and will at the same time improve the chances for desirable reproduction by the removal of the shade and root competition of the large trees. The growing condition of dense second-growth stands also can be improved by thinnings made to produce mine timbers.

COOPERAGE

Cooperage, particularly the manufacture of slack barrel staves and headings, is of some importance locally in the southern Appalachian region. In 1925 (*72*) about 275,230 slack barrel staves and 37,120 sets of headings were manufactured in the States wholly or partly included in the region. Forty per cent of the staves were made in Virginia.

Slack cooperage uses a considerable variety of woods in relatively small sizes for both staves and headings. Red gum is the most extensively used species for staves and pine for headings. Other species used for both purposes are elm, beech, maple, birch, cottonwood, ash, oak, and chestnut. This industry presents an opportunity for utilizing trees cut to improve the forest or to thin young or middle-aged stands.

Tight cooperage is made almost wholly from white oak, the only other species used to any extent being red oak. Since the nature of the product places high requirements upon the quality of the wood, the tight-cooperage industry competes with lumber production for the use of high-grade white oak and affords little opportunity for improved utilization.

FIREWOOD

Statistics on the use of wood for fuel gathered in 1908 (*47*) and in 1924 (*72*), indicate that the group of States which includes the southern Appalachian region consumes extremely large quantities of firewood, amounting in these two years, respectively, to 36 and 37

per cent of all the firewood consumed in the United States. Of this quantity, 50 per cent undoubtedly was taken from the region itself. According to these estimates, the output of firewood in the region decreased from about 15,380,000 cords in 1908 to 6,745,000 cords in 1924. It should be noted, however, that the 1908 estimate was for total consumption of fuel wood, whereas that for 1924, made in connection with the special United States census of agriculture (1925) was only for the quantity of fuel wood cut on farms. In 1908, 90 per cent of the consumption was on the farms and the remainder mostly in cities of less than 30,000 population.

Because of the greatly improved roads throughout the region, permitting delivery of coal by motor truck to many of the farms, it is likely that the consumption of wood for fuel has decreased somewhat since 1908. On the other hand, the same easier means of transportation has probably increased the use of wood in the cities. Firewood is likely to remain an important commodity in the Southern States, where furnace heating is much less common than in the North. The largest home use of farm woods is for firewood.

In the mountains considerable firewood is cut on the larger holdings of timberland. Many sales of firewood are made on the national forests. These are either improvement cuttings or thinnings, the former removing defective trees and waste material on cut-over areas, the latter taking a part of the trees from dense stands of second growth. Examples of stands thus thinned for firewood are to be found on the national forests, especially near towns and small cities. Some of the best are near Edinburg and Buena Vista, Va., on the Shenandoah and Natural Bridge National Forests.

OTHER PRODUCTS

In addition to saw logs, crossties, firewood, pulpwood, tanning-extract wood, cooperage stock, and mine timbers, which make up most of the wood volume taken annually from the southern Appalachian forests, are a number of other products of less importance Chestnut of suitable size and form is in demand for telegraph and telephone poles. The appearance of the chestnut blight stimulated active cutting for poles in many localities. Chestnut also furnishes a large number of fence posts and rails. The supply of these, as of the chestnut products previously discussed, may be expected practically to disappear within the next 10 or 15 years as a result of the blight.

Among the lesser products are dogwood and persimmon bolts for the manufacture of shuttles, spindles, and golf-club heads (*17*); hickory for golf club and other handles and for spokes; black locust for fence posts, insulator pins, and small poles (*18*); and a variety of small trees for novelties and rustic furniture. Some of these products are only locally important, while others provide a good market for material of proper kinds and dimensions over most of the region.

NEED FOR CONTINUOUS PRODUCTION

The figures for the annual output and consumption of forest products that have been quoted amount to a total of 6,000,000,000 board feet, as shown in Table 1. Since they are for different years and

were collected in different ways they afford only a very general approximation of the actual consumption of forest products in the region. The quantities shown are probably conservative, since it may be assumed that considerable material escaped the census takers and that the consumption as a whole has remained fairly constant within recent years. Table 1 does not give figures for the consumption of chestnut tanning-extract wood, since this, because of the chestnut blight, does not appear to be a replaceable resource. All of the other products can be placed upon a continuous basis of production; although, as will be shown later, only with greatest care can they be made perpetually available in the total amount shown.

TABLE 1.—*Estimated present annual production of lumber and other forest products in the southern Appalachian region (converted to board feet)*

Product	Quantity	Product	Quantity
	Board feet		*Board feet*
Lumber	2,225,000,000	Railroad ties	70,000,000
Fuel wood	3,250,000,000	Cooperage, poles, and other products	30,000,000
Pulpwood	225,000,000		
Mine timbering and ties	200,000,000	Total	6,000,000,000

To supply an annual demand for forest products approximating 6,000,000,000 board feet there are three classes of forest to be drawn on—virgin forest, cut-over forest, and second growth. The rapid rate at which the original virgin forest has been cut and the small area remaining clearly indicate that what is left will not last long. On the cut-over areas, as will be shown later, the present merchantable stand is altogether inadequate, even where sufficiently consolidated to justify logging. Future prospects for a continuous forest production adequate to meet regional requirements must rest, therefore, with the second growth.

A study of the yield capacity of well-stocked second growth, to be presented in Tables 8 and 9, makes it evident that the forests of the region will supply more than the estimated needs provided the destructive methods of utilization that are still widely practiced are supplanted by methods giving adequate protection and care to insure continuous timber production. According to Table 9, 310 board feet is the average annual growth per acre of 80-year-old, well-stocked second growth on Site II. Applying this yield to the 7,000,000 acres estimated as the total area of the more productive sites in the mountains gives a theoretically possible annual growth, without any treatment except protection from fire, of 2,170,000,000 board feet per year. Similarly, representing the annual growth on the drier sites by 90 board feet per acre—the average annual growth at 80 years shown for Site IV in the table—the yield of the 14,000,000 acres of drier site in the mountains would be 1,260,000,000 board feet per year. These figures are, of course, purely theoretical and are on a somewhat doubtful basis of area, since it is by no means certain that the sites for which the yields are selected truly represent the areas indicated. Furthermore, the forest under its present handicaps of fire damage, chestnut blight, insect damage, and unmerchantable large trees left standing after logging is totally incapable of supporting

this growth. But the estimates at least give some indication of the maximum possible production of the mountain timberlands if each acre were producing to capacity. For the whole mountain territory, excluding the spruce-fir forest as of relatively insignificant area, the annual output would be 3,430,000,000 board feet.

This leaves an annual deficit of about 2,600,000,000 board feet to be supplied by the forests of the plateaus and valleys, which aggregate about 40,000,000 acres. The annual growth necessary to make up this deficit would not have to be much more than 62 board feet per acre, which, as shown later in Table 9, could be supplied on average soils by raising stands to an age of only 40 years. Thus it is evident that the forest soils of the region are potentially capable of supplying all present needs, as far as quantity of product is concerned, with something to spare.

The actual present growth rate on southern Appalachian forest lands as a whole is obscured by lack of specific data, which could be obtained only by conducting a comprehensive survey. Examinations of many tracts scattered through the region indicate that a large part of such growth as is taking place is distributed among trees of little or no commercial promise. Such trees fall chiefly into the classes of large unmerchantable rejects from past logging, and smaller trees rendered defective by fire, decay, insects, or other causes. As will be seen in Table 6, the representative cut-over areas studied by the Appalachian Forest Experiment Station are only half stocked even with the unmerchantable trees figured in. Although many excellent small stands are scattered throughout the region, it is probably safe to say that the southern Appalachian timberlands as a whole are not making one-third of the growth which the soils are capable of maintaining. If this is the case, the present total annual growth for the whole region is far below that necessary to support the present annual consumption.

Part of this deficiency is doubtless temporary, for the rate of growth will increase as the reproduction on cut-over areas attains tree size. Such an increase, if it is to be of any value, is contingent upon protection from fire. Furthermore, it will not bring the growth rate up to the level of that in well-stocked second-growth stands so long as defective trees are allowed to monopolize a considerable share of the growing space.

The important facts relative to the future supply of forest products in the southern Appalachian region may be summarized as follows:

The yearly output of lumber and other forest products in the region approaches 6,000,000,000 board feet. Most of this supplies local industries and domestic needs; that which is exported brings wealth to the region. It comes partly from old-growth forest, virgin and culled, and partly from second growth that has reached commercial size. The utilization of mature old growth, if so cut as to ensure replacement with vigorous second growth, is logical and necessary. It results in substituting an active for a stagnant condition. If improperly taken, the result will inevitably be to perpetuate and extend the present growth deficit. This is true also of the second growth, and here there is the added possibility of waste of material in an active state of growth.

About 90 per cent of the mountain timberland is more or less depleted of merchantable timber. The natural replacement with thrifty second growth is handicapped by defective and unmerchantable trees left standing after logging. Forest fires, and to some extent insects, have killed or seriously damaged the smaller trees and reproduction over much of the area, converting seedling into sprout growth. Young stands on clear-cut or heavily cut-over areas grow much more rapidly than old-growth forest on corresponding sites. They produce yields comparable in amount to those of the virgin forest and in much shorter time. This growth can be increased in quality as well as quantity by the right kind of treatment. Protection from fire is the first essential.

Continuous timber production in the southern Appalachian region is principally a matter for private initiative, for over 90 per cent of the timberlands are privately owned.

TIMBER GROWING AND THE PROBLEM OF LAND USE

The timber-supply problem, as a matter of public importance chiefly in the hands of the private timberland owners, is one of getting an income from the land. Raising forest products may be a partial source of income on land held for other purposes as well, or it may be the only means of making the land pay. In either case the possibility of financial success should not be prejudiced by avoidable difficulties. One of these is the system of annual taxation of timber now in effect over most of region.

The annual tax on the value of standing timber may be partly responsible for indiscriminate and wasteful cutting in the past and may, if continued, affect unfavorably the holding of growing timber for future cutting. Under any circumstances the annual property tax on land and timber is not adapted to the development of forestry on cut-over lands, since during this period of development the returns will naturally be lower than when the forest is brought to a fully productive condition. A more appropriate system is greatly needed. The forest-tax situation, as part of the general rural-tax problem, will benefit from any measures taken to reduce excessive taxation of rural land and to insure a more equitable distribution of the cost of supporting schools and roads. Measures of various kinds have been proposed and to some extent put in effect for the purpose of relieving immature timber of the property-tax burden. At the present time the whole subject of taxation methods applicable to forest lands is under investigation by the forest taxation inquiry of the Forest Service, the purpose of which is to develop a satisfactory form of forest taxation.

Forest lands in the southern Appalachian region are customarily bought and sold at prices that have no definite relation to the income that might be obtained from them if they were to be systematically devoted to the raising of timber crops. The actual values of these lands must be fixed by the income to be derived from them under continuous forest production. Forest-land values will naturally be affected by the accessibility of the land and its quality as determined by the rate of growth and the value of the products it can supply. Thus there will be considerable difference between dry and moist

lands and between areas difficult and easy of access. Doubtless the true values based on continuous production will often be lower than the actual present prices at which the land has come to be valued as a result of recent transfers. For the better soils, however, the true value may sometimes be higher than the present sale price.

The uses of mountain forest lands for purposes other than timber production are few. Where they exist these uses often tie in very closely with commercial timber growing and in such combinations serve to increase the profits from the forest. For example, on coal or mineral lands held in fee, a well-managed forest is an almost indispensable asset for the duration of the operation; and after the mining operation has closed down the land can still be made to yield an income if the forest has been under management for sustained production. Another common reason for holding mountain lands is their value for recreation, hunting, and fishing. For these uses fire prevention is essential, as it is in the raising of timber. Timber growing can be conducted to great advantage as one source of revenue on lands held for recreational purposes.

Still another important use of mountain forests is for the protection of stream heads, and thus of commercial and city water supplies, electric-power reservoirs, and the navigability of streams. The influence of the forest in restraining flood waters and preventing erosion is vital to the welfare of the southern Appalachian region. It affects particularly the maintenance of reservoirs for town and city water supply and for power production. Power production has reached large proportions in the region. According to estimates made by the United States Geological Survey, the potential water power available 90 per cent of the time in the States wholly or partly included in the southern Appalachian region amounts to nearly 4,200,000 horsepower, or 11 per cent of the potential water power of the United States. The 401 power plants in the region, with a capacity of 100 horsepower or more, now develop a total of 2,924,237 horsepower. Most of this power is in streams that head in the southern Appalachian Mountains. Much of it is developed direct from the streams, without artificial storage in reservoirs. Power plants thus supplied must use fuel as a supplement to water power to a greater extent than if reserves of water were available during low-water periods in the streams. Unbroken forest on the watersheds will maintain a more regular and continuous stream flow than can be supplied by watersheds that have been heavily logged, cleared, or burned (*52*, *75*). Where reservoirs are employed their length of service depends upon the rate at which they become filled with silt. This in turn depends upon the rate of erosion above the reservoir. The best protection that the slopes could have against erosion is dense, unburned forest. (Fig. 2.)

The most severe erosion takes place when the mountain slopes are cleared and cultivated (*8*). Small farm patches on steep mountain sides are a common sight in many parts of the southern Appalachians. Plowing conceals the effect of wash from these cultivated slopes, but gullies quickly begin to form when such fields are abandoned. (Fig. 3.) The yearly wash of soil from an acre of land on the Yadkin River above Salisbury, N. C., has been computed (*1*) to average more than 850 pounds. Of this more than 125 pounds is organic matter,

F166333

FIGURE 2.—The beginning of erosion on skid trails, one year after horse logging in a spruce-fir forest

F12234

FIGURE 3.—The effect of surface run-off on a slope that was cleared, cultivated, and abandoned

the remainder being mineral soil. The organic matter is humus, chiefly from farming soils, and where this is the case it must be replaced if the soil is to be made productive.

In the hilly and rolling land below the mountains, erosion is especially conspicuous on abandoned farm lands. Ashe (*4*) points out that, although the proportion of cleared land on the watersheds is apparently not excessive, the condition and situation of much of it tend to jeopardize not only the value of the rivers, but the permanency of the soil as well. Unfavorable soil conditions have become far more general since 1880. The cultivation of extensive areas of hill country below the mountains, especially of the red clays in the extreme South, ceased between 1880 and 1900. The rural population moved to the factory towns; the negro labor immigrated to the cities. The surface of the farm land abandoned in this manner was quickly compacted and lost its porousness. Only a small portion of the heavy rains is absorbed by it, and much water that should be absorbed runs off, augmenting the floods. The springs formerly fed from the water stored in the soil have failed. The land itself has eroded in deep gullies.

Watershed protection is thus unquestionably an important object of timberland management in the mountain region, while in the plateau and valley regions the improvement and extension of farm woods to check erosion and conserve moisture are correspondingly urgent. In both situations, fire prevention, especially for the dry southerly exposures, is imperative. In well-stocked unburned stands on south slopes light cutting at rather long intervals can be safely practiced, but heavy cutting is almost certain to result in severe soil washing.

Thus forest protection and good management will benefit the region not only by providing permanent supplies of good timber but also by putting otherwise idle or half-productive land into active, remunerative use; by replacing a false with a true productive basis of land valuation; by maintaining permanent water resources and improvements for power development and city water supplies; by improving scenic values and recreational facilities for hunting, fishing, and camping, and thus tending to increase the attractiveness and popularity of the region to its own citizens as well as to tourists. The possibility of such public advantages to be gained through good forest management places forestry among the most important internal economic measures that present themselves to the people of a state or nation.

FACTORS THAT AFFECT CONTINUOUS TIMBER PRODUCTION

The measures used to obtain and secure continuous timber production will depend upon local conditions of timber and reproduction, conditions that for many reasons are extremely variable. The most important conditions to be considered are the species found in the stand (forest composition), the number of trees per acre (forest density), the present condition of the forest, the facility with which the various species reproduce themselves, and the growth rate of the various tree species. These conditions are in turn influenced by soil,

climate, direction of exposure, past logging, fire, insect depredations, and chestnut blight. Such influences affect the density, size, and promise of the young timber and reproduction. The conditions thus set up are so complex and variable that several different kinds of treatment may be required within a relatively small area.

COMPOSITION OF THE FOREST

About 140 species of trees are native to the Appalachian region. Of these about 60, listed in the Appendix (p. 87), are important commercially. All but 10 of the species are broad-leaved (hardwoods). The combinations in which these species are found (forest composition) are extremely varied, especially in the mountains. Many forest types are found (*56*), some clearly marked, others more complex and intergrading with each other. Although the best forest management will designate more than one kind of treatment within a single forest type, the types can be conveniently grouped for general description into four classes—moist slope and cove, dry slope and ridge, spruce, and plateau and valley forests. The first three make up the forests of the mountains.

MOUNTAIN FORESTS

MOIST SLOPE AND COVE FOREST

Cool, moist coves and shaded northerly slopes comprise probably a third of the mountain-forest area. This class of forest has three fairly well-marked divisions—cove, lower moist slope, and upper moist slope. The cove forest is found at altitudes of 2,000 to 4,000 feet in the southern mountains; lower in the north. It sometimes runs heavily to hemlock (pls. 3 and 4), sometimes to yellow poplar, but more commonly it is a varying mixture of many species, among which are white pine, basswood, black gum, black birch, cucumber magnolia, various hickories, walnut, red maple, buckeye, black locust, black cherry, sycamore, silverbell, sourwood, holly, and dogwood. This forest is now found mainly in the narrow coves and their adjacent lower slopes, the broader coves and valleys having long since been cleared for agriculture. Where found, it represents the best opportunity for profitable forest management in the mountains. These stands contain the largest number of valuable species, their rate of growth is most rapid, and they recover most readily from cutting and fire. The lower moist-slope forest occurs on northerly slopes at about the same altitudes as the cove forest. Chestnut and several species of oak and hickory form the bulk of the timber, but a number of the cove species are usually more or less abundant in mixture. The upper moist-slope forest, extending to altitudes of 5,000 feet or more in North Carolina, but lower in West Virginia, is a varying mixture of "northern hardwoods" (yellow birch, sugar maple, and beech), hemlock, buckeye, and several other species found also at lower elevations.

DRY SLOPE AND RIDGE FOREST

Dry slope and ridge forest (pl. 4, B) is found chiefly on southerly or westerly exposures extending up to the edges of the upper moist

slope and spruce forests, but often covers east slopes well around to the northeast. It is the most extensive of the three groups. A timberland inventory would probably place nearly two-thirds of the total forest area in this class. The forest is composed of the more drought-resistant species, largely chestnut oak, scarlet oak, white pine, pitch pine, and mountain pine, with black gum, red maple, hickories, dogwood, and sassafras in mixture. The dryness of these exposed sites favors fires, which here impoverish growth conditions more readily than in more moist situations. As a result the stands are very commonly scattered and defective, growth is slow, and reproduction is likely to be largely of inferior species. On large areas of young second growth the majority of the trees have become infected with heart rot through fire scars. Although such stands may seem to be growing thriftily, they actually represent an increasing liability and a difficult problem of forest management.

SPRUCE FOREST

The spruce forest is found at altitudes of over 4,500 feet in the mountains of North Carolina, Tennessee, and Virginia, and at altitudes of over 3,500 feet in West Virginia. Red spruce is the predominant species. In North Carolina and Tennessee the spruce is commonly mixed with southern balsam fir; at the highest altitudes the fir often predominates or occurs in pure stands. In West Virginia a common associate is hemlock. Hemlock and northern hardwoods, particularly yellow birch, mix freely with the spruce along the lower fringes of this forest throughout its occurrence in the region. There are typical examples of spruce forest at altitudes of 5,000 feet and over in the Black and Balsam Mountains of North Carolina and in the Smoky Mountains from Clingmans Dome northward along the border of Tennessee and North Carolina to Mount Guyot. (Fig. 4.) Smaller stands occur on a few isolated peaks in North Carolina, Tennessee, and the southern part of Virginia, east of the Appalachian Valley.

In West Virginia, spruce once covered considerable areas in the mountains, but all except a few scattered remnants of the original spruce forest have now been cut. Similarly in the Black and the Balsam Mountains, and in isolated areas, much of the spruce-fir type has been destroyed by logging, fire, and the southern pine beetle. The largest remaining body of original forest is probably one of about 45,000 acres in the Smoky Mountain National Park.

The spruce forest is unimportant as a source of forest products for the region as a whole, though it has considerable importance in particular localities. Its value as a protective cover for watersheds and as a scenic element increasing the attractiveness of the mountains for recreation are strong reasons for the preservation of this forest where it occurs and for its reestablishment on the areas from which it has disappeared.

PLATEAU AND VALLEY FORESTS

In composition the plateau (fig. 5) and valley forests are much like the dry-site and lower moist-site hardwoods of the mountains, but with a greater proportion of stands which run heavily to pine.

F166345

FIGURE 4.—A virgin spruce forest at high altitudes in the mountains. The trees in this dense forest vary greatly in size and age, making light partial cuttings desirable

A few of the common mountain trees—pitch pine, mountain pine, chestnut, basswood, buckeye, and some others—are uncommon or only locally important in the plateau forest, while several species that are important in much of the plateau and valley region—red gum, southern red oak, shortleaf pine, and Virginia pine—are rare or absent in the mountain forest.

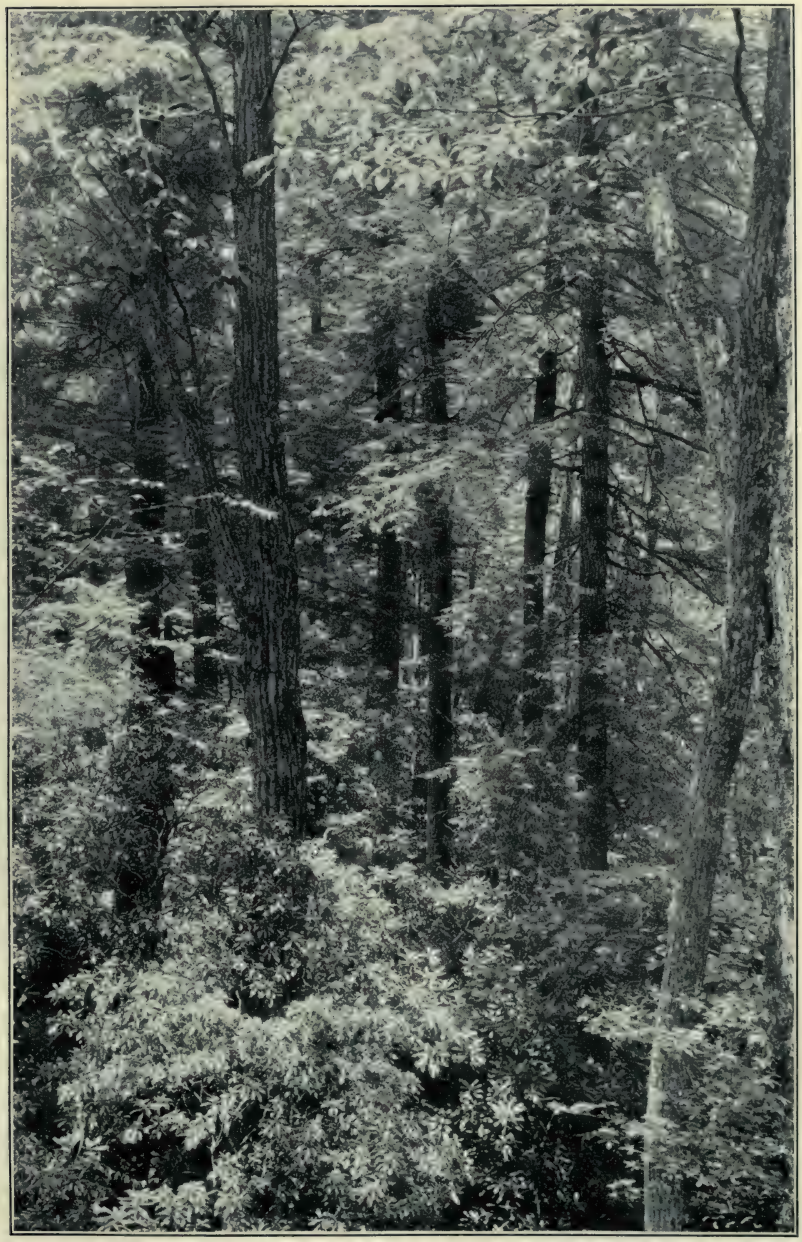
Much of the same difference in composition exists between moist and dry sites as is found in the mountains. Protected ravines and northerly slopes have stands of cove hardwoods resembling those of the mountains, and yellow poplar grows well on the moist sites. Most of the watercourses are lined with river-edge hardwoods, chiefly river birch, sycamore, black willow, and red maple. Dry soils have stands prevailingly of oak, pine, or pine and oak mixed. The common oaks are southern red, scarlet, black, white, and post

F5296

FIGURE 5.—Plateau forest—a characteristic irregular, culled stand of oaks and shortleaf pine on a dry site

oaks, and they are usually mixed with hickories of several kinds and with other species, of which black gum is one of the commonest. Nearly pure stands of southern red oak are quite common in some parts of the region, and post oak sometimes predominates on poor soils.

Of the pines, shortleaf is the species most generally distributed, but Virginia pine ordinarily supplants it in northeastern Virginia and Maryland and occurs in places throughout the piedmont, commonly in pure stands. Along the eastern and southern borders of the piedmont and in the southern part of the Appalachian Valley, old-field loblolly pine is quite abundant on fresh to moist soils. Longleaf pine intrudes into the piedmont at places in the southern portion, but no longer in important stands. Pure stands of red cedar are frequent, particularly in the southern part of the Appalachian Valley.



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SHADE MUST BE TEMPERED TO HARDWOOD REPRODUCTION

Virgin hemlock and hardwood cove forests cast heavy shade that must be greatly reduced if good hardwood reproduction is to be obtained. In this case, also, the shade is reinforced by an undergrowth of rhododendron and other shrubby species.

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TWO MOUNTAIN FOREST TYPES IN THE SOUTHERN APPALACHIANS

A, Culled hemlock and hardwood cove forest; B, dry slope and ridge hardwoods.

While the typical farm woods of the plateaus are small holdings, usually in strips back from the roads, and surrounded by cultivated fields, meadows, roads, or brush land, those of the foothills and the many parallel ridges in the Appalachian Valley are generally contiguous in larger bodies on the steeper and less fertile soils. On the lower interior plateaus of the mountains, in the southern part of the region, these woodlands reach altitudes of about 2,500 feet, and merge with the mountain forests.

The plateau and valley woodlands have been more altered by settlement than the mountain forests. Many of them are dense stands of second growth that have come in on abandoned fields. Pine now occurs almost entirely in second-growth stands, pure or mixed with hardwoods. On moist sites, promising second-growth stands of yellow poplar and other valuable hardwoods are numerous. The remaining old-growth stands have generally been culled of their best species.

RELATIVE VALUE OF THE SPECIES

One fact that has been repeatedly demonstrated in the logging history of the southern Appalachians is that the commercial values of the different tree species are not stable. New developments are continually arising to bring little-used species into economic importance. The species that can be logged profitably have constantly grown in number until now there are few of the different southern Appalachian trees that are not of some commercial promise. Since this extension of utilization is likely to go on indefinitely, the basis for selecting the species to be encouraged for future production should be not so much the present demand as the fundamental qualities of growth rate, mature size, form, soundness, vigor, and the technical adaptability of the wood. The last-named quality affords a basis for judging what the prospective commercial demand may be. Trees having wood qualities adaptable to more than one type of use are the most likely to maintain a stable value.

Tree species can not be expected to develop their best qualities on soils unfavorable to them. Species adapted to moist soils will not compete successfully on dry sites with dry-site species, and it would be a mistake to favor yellow poplar, for example, except on a relatively moist soil. Better a vigorous stand of species now rated as less valuable than a poor, unthrifty growth of the best species. On good soils, however, it would be a mistake to permit the land to become stocked with species that will neither grow as rapidly nor yield as valuable products as the better of the moist-soil species.

The question of desirability for timber growing can not be answered by listing the species in any precise order of relative merit. Local circumstances will often affect the desirability of certain species. The general values of the species for forest management, however, are indicated in Table 2, in which the "desirable" and "less desirable" species are grouped by their suitability for moist or dry sites.

TABLE 2.—*Southern Appalachian trees classed as to desirability for timber production*

MOIST-SITE SPECIES

Desirable timber species [1]	Less desirable species	
	Timber species	Minor species [2]
Ash (sp.)	Beech	Birch, river.
Basswood (sp.)	Buckeye	Blue beech.
Birch, sweet	Butternut	Cherry, pin.
Birch, yellow	Chestnut [3]	Chinquapin.[3]
Cherry, black	Coffeetree	Crab apple.
Fir, southern balsam	Elm (sp.)	Dogwood.[3]
Gum, red	Gum, black [3]	Hawthorns.
Hemlock, eastern	Hemlock, Carolina [3]	Holly.
Hickory, mockernut	Hickory, bitternut	Hophornbeam.
Hickory, pignut [3]	Honeylocust	Magnolia, mountain.
Hickory, shagbark	Maple, red [3]	Magnolia, umbrella.
Locust, black [3]	Maple, silver	Maple, striped.
Magnolia, cucumber	Oak, pin	Mountain-ash.
Maple, sugar	Oak, shingle	Mulberry, red.
Oak, chinquapin	Oak, water	Persimmon.[3]
Oak, red	Sycamore	Redbud.
Oak, white		Rhododendron.
Pine, northern white [3]		Sassafras.[3]
Poplar, yellow		Serviceberry.[3]
Spruce, red		Silverbell.
Walnut, black		Sourwood.[3]
		Willow, black.

DRY-SITE SPECIES

Cedar, eastern red	Chestnut [3]	Chinquapin.[3]
Hickory, pignut [3]	Gum, black [3]	Dogwood.[3]
Locust, black [3]	Hemlock, Carolina [3]	Oak, blackjack.
Oak, black	Maple, red [3]	Persimmon.[3]
Oak, chestnut	Oak, post	Sassafras.[3]
Oak, southern red	Oak, scarlet	Serviceberry.[3]
Pine, pitch	Pine, mountain	Sourwood.[3]
Pine, shortleaf		
Pine, Virginia		
Pine, northern white [3]		

[1] Most of the species that are desirable on moist sites are less desirable where they occur on dry sites.
[2] Generally small trees.
[3] Species common on both moist and dry sites.

The grouping in Table 2, of course, implies consideration of quality and condition of the trees as well as of their location on soils suitable to them. For example, seamy old hickory is still a drug on the market, but second-growth hickory has great promise for a number of uses. Special adaptability to site may alter the ratings of desirability shown in the table. Thus river birch, sycamore, willow, and silver maple are the characteristic trees of the river-edge forest, where they may be among the most desirable of all species. Of the more abundant species there are only a few that because of slow growth, small size, or defect do not seem to have much commercial promise. Among these are sourwood, post oak, blackjack oak, and scarlet oak. Even these have certain values when large and sound enough, and should be classed only as relatively inferior to other species. Of the small trees, dogwood and persimmon have high value for small products (*17*), but since they grow slowly and generally attain only a small size a high rating can not be given them. The reproduction of the small species, particularly of dogwood and sourwood, is often a serious hindrance to the reproduction of more valuable species.

Of the larger timber trees, chestnut, the most abundant and generally useful species in the southern Appalachians, has been reduced within the last 20 years by the chestnut blight to a distinctly valueless species for timber production. In the reproduction on cut-over or burned areas its vigorous sprouting capacity interferes with the growth of other species without offering a justifiable hope that the chestnut will grow to merchantable size.

Of the moist-site species, yellow poplar (*3*) has the highest general rating of value, and its wood will probably always be in demand. Poplar saw-log trees have a high value, and those too small to yields logs, such as thinnings from too dense stands, can be used to advantage for paper pulp. On the moist soils to which it is adapted poplar is one of the most rapidly growing of the southern Appalachian trees. It is particularly free from any serious insect enemies and diseases. It reproduces poorly by sprout, but its seedling reproduction under proper conditions is excellent, as in Plate 5, B. The seed must not dry out and must come in contact with mineral soil; also the seedlings should have ample light from above.

Other valuable and relatively abundant species of the moist sites are northern white pine, red oak, and white oak. Northern white pine (*21*) is rather irregularly distributed, and there are considerable areas where it is rare or absent. It reproduces well, with frequent though not annual seed years, but the early growth of the seedlings is so slow that many are likely to be killed by the competition from any rank growth of hardwood sprouts and seedlings, shrubs, or herbs. Later growth is very rapid. Plantations of white pine on the Biltmore Estate, N. C. (*28*), show a more rapid growth than is indicated for the best quality of natural white pine stands in New England.

Northern white pine is not very fastidious and shows a capacity to succeed on some of the higher slopes which are not too dry or too exposed to winds. In the southern Appalachian region it has hitherto appeared relatively free from serious insect or fungous enemies, but elsewhere in its range a very serious disease, the white pine blister rust (*Cronartium ribicola*, Fischer), has done much damage, since 1900 or earlier, when it was imported from Europe on white pine seedlings (*57*). Fortunately wild currants and gooseberries, the alternate hosts of the disease, are generally rare at the altitudes at which northern white pine grows in the southern Appalachian region. Safety from the disease, however, is a very good reason for a strict quarantine on shipments of white pine planting stock from outside the region. Seedlings for planting in the southern Appalachians should be grown from seed within the region.

Red oak (*67*) occurs scatteringly through the upper coves of the lower moist-slope forest, and, in the form of short trees of fairly rapid growth, on some of the higher, relatively moist ridges. Like those of the other oaks, its acorns are subject to destruction by insects, rodents, and other animals, and require moist storage over winter and favorable soil conditions to insure germination in the spring. Seedling reproduction is likely to be scanty, but red oak sprouts well from small stumps.

White oak (*27*) reaches best development in the coves and on the lower moist slopes but is also found on the drier slopes and ridges.

It grows especially well in the coves of the Cumberland Plateau. However, as its growth, at best, is slow and its fall-germinating acorns are destroyed in large quantities by insects and rodents, its reproduction is not always to be depended upon.

Basswood (*12*, *64*) is a valuable species that is abundant in many places in the mountains. White ash (*59*, *60*, *69*), black cherry (*65*), black walnut (*7*, *11*, *13*, *41*, *70*), and cucumber magnolia are moist-site species of high commercial value, but they are not very abundant. These are among the best species to be encouraged on good soils. White ash is not so valuable as in the more northerly part of its range or in the Ohio Valley, but it reproduces by seed much more freely than basswood, walnut, and cucumber magnolia. Black cherry makes a rapid growth and is of value where it occurs in quantity.

Eastern hemlock (*22*) is the most shade-tolerant tree in the southern Appalachian forests. For its best development it requires a good moist soil and a cool, humid climate, like that of high altitudes in the mountains or of north-facing coves and slopes lower down. It appears to demand a certain amount of shade as a protection against the drying out of the soil and the loss of atmospheric moisture. The rate of growth is ordinarily slow, but young trees that get ample light grow rather rapidly, and shaded trees increase their growth rate considerably if the shade is lessened by the removal of adjacent trees. Eastern hemlock reproduction is not abundant in the southern Appalachians, probably because of ground fires and the consequent unfavorable conditions of the forest floor. Eastern hemlock lumber from this region is commonly regarded as inferior in quality to that from the North, but carefully graded lumber from especially good stands competes successfully with Pennsylvania (eastern) hemlock in Pennsylvania markets. Eastern hemlock is useful for wood pulp, and because of its ability to endure shade it is desirable as a mixture in the hardwood forest to increase the volume yield. Where small trees are found, or where good stands of advance growth exist, it is well to favor these.

Shagbark, mockernut, and pignut hickories (*9*, *46*, *68*) are species of great value in some parts of their ranges, as in the Ohio and Mississippi Valleys. In the southern Appalachians the hickories as a group have never been rated highly and are frequently ignored and left standing by the loggers. The old trees have as a rule grown slowly and produced wood inferior in quality to that of rapidly growing second growth. In moist situations the better hickories, particularly shagbark and mockernut, have potential value and can well be favored.

Black locust (*18*, *66*), like chestnut, is so little exacting in its site requirements that it is found nearly everywhere in the forest below the spruce. It is common on both moist and dry soils and is one of the most rapid growers up to small-pole size. It is likely to be abundant in young stands, especially those which have sprung up after fires, but is relatively short lived in the forest. It is commonly overtopped and killed out by other species when 10 or 12 inches in diameter. The locust borer (*Cyllene robiniae* Forst.) does considerable damage in places, but is not usually a serious enemy of locust in mixed stands. Black locust has a high value for posts and small

poles because of the durability of the wood in contact with soil. Consequently it is important as an intermediate yield in the treatment of young stands. Black locust can be very easily raised from the seed. It has been successfully planted to stop erosion.

The trees which are characteristic of dry sites occur there because they are able to withstand dry conditions rather than through lack of adaptation to better soils. They all occur here and there on the moist sites, where they grow more rapidly than on the dry sites and sometimes monopolize small areas. They are generally of less intrinsic worth, however, and are to be discouraged on the good growing soils.

Chestnut oak (*20*) is the most desirable of the dry-site oaks. It is useful for saw logs, railroad ties, and tanbark. It bears abundant annual crops of acorns, which germinate in the fall, and it reproduces well by sprout. Black oak also is a good timber tree on soils not too poor for the production of saw-log trees. Scarlet oak, though of fine form, is unusually subject to heart rot and in many localities becomes worthless by the time it has reached a diameter of 12 or 15 inches. (Pl. 5, A.)

The dry-slope pines in the mountains are usually pitch pine and mountain pine. Shortleaf pine (*2*) and Virginia pine (*58*) replace them on the plateaus and foothills. Shortleaf pine is by all odds the most important up to altitudes of about 2,500 feet. It produces excellent softwood lumber, grows rapidly as compared with most of the dry-site hardwood species, and reproduces freely, especially where fires have killed back hardwood growth. The seedlings of all the pines start slowly, require much light, and, with the exception of shortleaf pine, do not sprout when killed back to the ground. Pitch, mountain, and Virginia pine are species of promise for pulpwood. They are not of much present value for lumber, but in mixture with hardwoods on the ridges and dry slopes they often grow so well as to suggest the desirability of encouraging them in the prospect of increased future value. Unfortunately, shortleaf and, to a lesser extent, the other dry-site pines are subject to destruction by the southern pine beetle (*Dendroctonus frontalis* Zimm.) (*31*, *51*), which appears to be particularly destructive in pure stands of pine.

Red maple, buckeye, and black gum, formerly almost entirely neglected in logging, have acquired a value for paper pulp where they are accessible to soda process mills. The maple and gum are common in the reproduction on dry as well as on moist cut-over lands.

Butternut, beech, and bitternut hickory have little present value in the southern Appalachian region. This is true also of sourwood, silverbell, sassafras, serviceberry, and the many species of hawthorn, chiefly because of their small size.

In the spruce forest the leading species are, of course, the native red spruce (*44*) and in the southern part of the region, southern balsam fir, the latter commonly increasing in abundance with increase in altitude. Commercially, the spruce is the better of the two. Its growth seems to be more rapid than that of the same species in New England. It yields excellent lumber and reaches large size; in the Smoky Mountains trees containing eight 16-foot logs, measured to a top diameter of 5.5 inches, are sometimes found. Spruce seeds heavily only at intervals of several years. Fir pro-

duces seed more frequently but not every year. Its growth is more rapid than that of spruce, but the tree does not reach so large a size. Fir is not so suitable for either lumber or pulp as is spruce, although its wood is used for both purposes.

THE YIELD OF THE FOREST

The differences in climate and soil which affect the composition of the forest also affect its density, growth rate, and yield. These differences are especially pronounced in the mountains where coves, ridges, and slopes of all degrees of steepness and exposure closely adjoin each other. Increases in the moisture of air and soil are ordinarily reflected by the presence of more rapidly growing tree species and larger numbers of trees of a given size per acre. The increase in the density of the stand tends toward the production of tall, straight, small-crowned stems, growing rapidly in height but slowly in diameter. (Pl. 4, A.) In the coves and on protected slopes the growth rate of the stand as a whole, owing largely to the greater height growth of the individual trees, is rapid as compared with that on the drier sites. Ridge tops with shallow, relatively dry soil will support only an open short-bodied stand of trees inclined to be crooked and defective. (Pl. 4, B.)

YIELD OF THE OLD-GROWTH FOREST

According to estimates and logging records, the original forest of the deep coves and shaded northerly slopes generally had a stand of from 15,000 to 50,000 board feet per acre, with an average of less than 25,000, taking into account all species and expressing the yield of tanning-extract wood and pulpwood in board feet. A 40-acre tract of cove hardwoods cut in 1912 near Lookingglass Rock in western North Carolina is said to have produced 40,000 board feet of yellow poplar per acre, with other species in addition. A yield of nearly 100,000 board feet per acre is attributed to a northern white pine stand cut years ago in Shady Valley, near the Virginia-Tennessee State line.

Outside of the coves the original stand was not so heavy. On fairly moist slopes it apparently ran from 7,000 to 15,000 board feet per acre, averaging about 9,000, while on the dry slopes the yield per acre was generally from 2,000 to 7,000 board feet, with an average of about 3,000. Authentic estimates of spruce in the Smoky Mountains give it an average yield of 18,000 board feet per acre, but many individual acres will run as high as 30,000 or 40,000 board feet.

Growth in the virgin forest is commonly slow, and if large areas are considered it is likely to be offset by decay. Most of the trees have practically ceased to grow in height and crown extension. The majority are mature and overmature, and such younger trees as have been able to fill openings where old trees have fallen are usually too much compressed by the crowns surrounding them to grow rapidly. Much of the growth that does take place is distributed uneconomically on poorly formed or defective trees. As compared with the active growth of young timber, the old-growth forest is in a nearly static condition.

YIELD OF REPEATEDLY CULLED FOREST

Over millions of acres in the southern Appalachians the forest has been repeatedly culled. A good idea of the resulting stand is afforded by Forest Service estimates for the eight national forests in the region, presented in Tables 3 and 4. The forests have a combined area of about 1,989,000 acres, which is a little more than 9 per cent of the entire wooded area in the mountains. They are distributed along the mountains from West Virginia to Alabama, so that the figures are fairly representative of the type of timberland mostly purchased for the national forests—cut-over land with a smaller stand of merchantable timber than is to be found on much of the other timberland in the region.

TABLE 3.—*Stand and distribution of saw-log timber in eight southern Appalachian national forests,*[1] *and percentage of species distribution by States*

Species	Stand	Distribution							
		West Virginia	Virginia	Tennessee	North Carolina	South Carolina	Georgia	Alabama	Total
Hardwoods:	*M bd. ft.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Chestnut	299,821	7	15	9	26		16		13
Yellow poplar	270,633	4	7	17	10	15	9	14	12
Chestnut oak	240,847	24	23	7	10	5	9	4	11
White oak	179,539	13	8	4	6	6	13	21	8
Mixed oak [2]	168,926	4	8	4	9	9	14	6	7
Red oak	137,022	5	8	4	6	4	11	1	6
Hickory	57,167		3	1	4	2	3	6	3
Maple	22,838	11			3				1
Basswood	17,196	1			2				1
Yellow birch	11,277	2			2				
Beech	10,135	5							
Buckeye	7,822		1	3					
Cucumber	4,174								2
Ash	3,992				3				
Black locust	1,260	1							
Black cherry	1,066								
Black walnut	769								
Miscellaneous	122,239	3	4	10	3		2	3	5
Total	1,556,723	80	77	59	84	41	77	55	69
Softwoods:									
Yellow pine [3]	350,190	7	7	16	5	48	17	40	16
Hemlock [4]	250,546	7	8	20	9	4	3	5	11
Northern white pine	98,057	4	7	5	2	7	3		4
Spruce and fir	3,942	2	1						
Total	702,735	20	23	41	16	59	23	45	31
All species	2,259,458	100	100	100	100	100	100	100	100

[1] Monongahela, Shenandoah, Natural Bridge, Unaka, Pisgah, Cherokee, Nantahala, and Alabama National Forests. Figures are based upon estimates of 1930. The total area of these national forests is 1,988,563 acres (June 30, 1929).

[2] Largely scarlet and black oaks.

[3] Shortleaf, Virginia, mountain, and pitch pines.

[4] 60 per cent of the total hemlock was reported from the Cherokee National Forest alone.

The total stand of saw timber reported on these eight national forests averages about 1,100 board feet per acre. The estimates for products other than saw logs are given in Table 4. These products (except tanbark) are the equivalent of 2,337,000,000 board feet. "Secondary" products thus amount to more than 50 per cent of the entire merchantable stand on the national forests. Much of the larger part is in mature and overmature timber and represents the salvage-

able material that should be cut for the best development of the second growth.

TABLE 4.—*Stand of products other than saw logs in eight southern Appalachian national forests, based upon estimates of 1930*

Form of product	Total stand	Form of product	Total stand
	Cords		*Pieces*
Extract wood	2,588,000	Railroad ties	3,293,000
Fuel wood	918,000	Posts	2,167,000
Pulpwood	493,000	Poles	168,000
Miscellaneous	24,000		
			Cords
Total cordwood products	4,023,000	Tanbark	613,000

While the yield on all cut-over land is generally small, the growth rate is much more rapid than in the virgin forest, owing to the rapid development of reproduction after heavy logging and to the increased growth of pole-sized trees left standing. The effect of repeated culling, however, has been to reduce the proportion of the best species and to diminish the seed supply upon which a natural seedling reproduction for the future stand is dependent. The abundance of the less valuable species is proportionately increased. (Pl. 8.) In order to determine the existing conditions of remaining trees and reproduction on the usual type of repeatedly cut-over, but not clear-cut, hardwood lands that have escaped recent fires, the Appalachian Forest Experiment Station has undertaken a survey of such areas by means of representative sample plots. The general method and some of the results have been discussed by Buell (*14*). The survey has thus far covered 14 cut-over areas in the mountains of Virginia, North Carolina, and Tennessee, and the results afford an idea of the character and promise of the present stand and reproduction. These results have been summarized in tabular form for five of the important hardwood forest types, the species being grouped as "desirable" and "less desirable," corresponding in general to the lists in Table 2. Table 5 shows the number of trees per acre 3.1 to 9 inches d. b. h. and those above 9 inches. The distinction between "good" and "poor" trees in this table is based upon straightness and soundness, although many of the trees tallied as "good" had small fire scars at their bases through which decay may perhaps have entered.

TABLE 5.—*Number of trees per acre in five important hardwood types on unburned cut-over lands in the southern Appalachians, classified according to size and quality of trees and desirability of species*

TREES 3.1–9 INCHES D. B. H.

Forest type	Desirable species		Less desirable species		Total	Basis [1]	
	Good trees	Poor trees	Good trees	Poor trees			
Dry slope and ridge:	*Number*	*Number*	*Number*	*Number*	*Number*	*Plots*	*Acres*
Black oak-scarlet oak type	20	7	30	20	77	12	5.5
Chestnut oak type	29	22	28	44	123	59	28.7
Moist slope and cove:							
Cove hardwood type	28	12	37	33	110	72	29.6
Northern hardwood type	10	11	16	23	60	12	4.9
Chestnut type	23	13	56	66	158	135	64.7

[1] The period since the last cutting varied from 2 to 19 years; 70 per cent of the area sampled had been cut over from 6 to 14 years.

F24362A F27329A

DENSE STANDS USUALLY FOLLOW TOTAL CLEARING

A, This second growth of dry-site hardwoods following clean cutting for charcoal wood is of scarlet and black oaks, 65 years old, about 60 feet tall, representing the growth on Site IV, as shown in Table 8 (Shenandoah National Forest, Va.); B, the dominant trees in this 67-year-old stand of second-growth yellow poplar on an old field averaged about 115 feet tall. It thus represents Site I as shown in Table 8. The stand was culled for saw logs in 1920, after the picture was taken. Pisgah National Forest, N. C.

F196303 F217096 F4140A

VARIOUS EFFECTS OF FIRE

A, Sprout reproduction of hardwoods after fire in the dry slope and ridge forest of pine and hardwoods; B, fire-damaged young trees are a continuing liability. Fire-scarred trees are subject to decay and should be cut or girdled to clear the ground for a better stand; C, a red oak tree broken down as a result of repeated fires and decay.

F232329 F230056

A, Cross sections of fire-damaged young oaks similar to those shown in Plate 6, B. The right-hand section represents a black oak severely burned 18 years ago and again 4 years ago. The white oak section (left) is from a 46-year-old tree burned 37 years ago and again 21 years later. Both scars are completely healed over. Active decay is present in both sections; B and C, fires destroy the leaf litter (B) in which they travel and which, were it allowed to decay, would contribute to the soil the organic matter that maintains its fertility, absorptiveness, and porosity. When the leaf mulch is destroyed by fire (C), mineral soil and tree roots are exposed

F238620

STAND LEFT AFTER HEAVY SELECTIVE CUTTING

Defective trees and inferior species not cut for lumber or ties were girdled. Natural Bridge National Forest, Va.

TABLE 5.—*Number of trees per acre, etc.*—Continued

TREES OVER 9 INCHES D. B. H.

Forest type	Desirable species		Less desirable species		Total	Basis	
	Good trees	Poor trees	Good trees	Poor trees			
	Number	*Number*	*Number*	*Number*	*Number*	*Plots*	*Acres*
Dry slope and ridge:							
Black oak-scarlet oak type	16	2	20	5	43	12	5.5
Chestnut oak type	17	7	5	7	36	59	28.7
Moist slope and cove:							
Cove hardwood type	18	5	0	7	39	72	29.6
Northern hardwood type	17	5	4	9	35	12	4.9
Chestnut type	10	4	12	8	34	135	64.7

These figures, obtained on what are believed to be typical cut-over areas, strengthen the impression given by Table 3 that the cut-over forests of the southern Appalachians are generally understocked. For the five forest types represented in Table 5 the volume of wood in all the trees above 3 inches d. b. h. falls between 16 and 28 cords per acre, as shown in Table 6. In the black oak–scarlet oak type, with an average of 9.7 inches d. b. h., the 120 trees per acre have a volume of 22 cords. With the same average diameter, a well-stocked even-aged second-growth stand on a comparable site would have double the number of trees and double the volume per acre.

TABLE 6.—*Estimated deficiency in stocking of stands on unburned cut-over lands when compared with well-stocked second growth of corresponding site quality and similar average diameter breast high* [1] *by forest types*

Forest type	Average cut-over stand 3 inches and over, diameter breast high			Well-stocked second growth			Estimated deficiency in volume of average cut-over stands	
	Trees per acre	Average diameter breast high	Volume per acre	Trees per acre	Average diameter breast high	Volume per acre		
	Number	*Inches*	*Cords*	*Number*	*Inches*	*Cords*	*Cords*	*Per cent*
Dry slope and ridge:								
Black oak-scarlet oak type	120	9.7	22	241	9.7	44	22	50
Chestnut oak type	159	7.6	16	326	7.4	31	15	48
Moist slope and cove:								
Cove hardwood type	149	9.2	26	318	8.8	53	27	51
Northern hardwood type	95	11.2	28	285	10.0	67	39	58
Chestnut type	192	8.0	24	352	7.8	41	17	41

[1] The figures for well-stocked second growth are interpolated from the yield tables from which Table 8 was prepared. Site IV values were used for the dry slope and ridge forest, Site II for cove hardwoods and northern hardwoods, and Site III for the chestnut type. The interpolation resulted in generally lower average breast-high diameters for the well-stocked stands than are shown for the cut-over stands. The volume deficiencies of the cut-over stands are therefore conservative except perhaps for the black oak-scarlet oak type.

In all five examples the indicated deficiency in wood volume ranges from 41 to 58 per cent. Since the 290 sample plots upon which Tables 5 and 6 are based were widely distributed through the mountain region they probably represent fairly well the prevailing condi-

tions on cut-over areas. The wood volume alone, however, does not tell the whole story, for a part of it is made up of defective trees and of trees of the less desirable species. The proportion of straight, sound trees of desirable species in the stand is shown in Table 7.

TABLE 7.—*Proportion of good trees (i. e., straight, sound trees) of desirable species in typical unburned cut-over stands, by forest type*

Forest type	Trees 3.1–9 inches diameter breast high		Trees 9.1+ inches diameter breast high		All good trees	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Dry slope and ridge:						
Black oak-scarlet oak type	20	26	16	37	36	30
Chestnut oak type	29	24	17	47	46	29
Moist slope and cove:						
Cove hardwood type	28	25	18	46	46	31
Northern hardwood type	10	17	17	49	27	28
Chestnut type	23	15	10	29	33	17

The evidence of overcutting brought out in Table 6 is emphasized throughout Table 7, for in not one of the forest types represented are as many as one-half of the trees straight and sound and of desirable species. Among the small trees the inferiority is the more pronounced. Three-quarters or more of the trees in this size class are of the less desirable species or defective; and these stands, not having been burned severely or recently, are presumably in better condition than the large areas of cut-over forest that have been fire-swept. The indications are therefore strong that the greater part of the southern Appalachian hardwood forest is far below its potential productive capacity.

The effect of repeated culling of the southern Appalachian forests at short intervals may be summarized as follows:

The best species were logged earliest and most persistently; this reduced their seed supply and decreased their abundance in the reproduction as compared with poorer species. Valuable species, particularly yellow poplar, have been cut heavily to very small sizes for pulpwood and other small products. This has reduced the quality of the second growth by increasing the proportion of the poorer species. The effect of cutting always the best species, large and small, is that of a constant attrition, perhaps not marked at any one time, but cumulative and tending toward the elimination not only of the trees themselves but also of all means for their natural reproduction in future stands.

Moreover, not only the best species but the best trees of all merchantable species have been cut, increasing the proportion of the poorest. Defective trees left standing in the southern Appalachian forest occupy thousands of acres in the aggregate and interfere with the continuity and success of second growth.

A third effect, which will be developed later, is the increase in the proportion of sprouts to seedlings, leading to deterioration of the stand.

In these effects are reflected the enforced economies and lack of incentive to better forest management that have characterized logging methods in this region in the past. Heavy competition resulted in

overproduction, low prices, and narrow profit margins. Under this pressure investments in timber and timberlands were depreciated for the period of operation, and no additional investment to maintain the lands in a productive condition was provided. What the forest might have been without this pressure will be discussed later.

YIELD OF SECOND GROWTH

The reproduction on heavily cut-over or clear-cut areas springs up into dense stands of second growth, broken only to the extent that large rejected trees of the old forest have been left standing. Stands that have followed total clearing are remarkably dense and uniform. (Pl. 5.) Where they have escaped fire damage such stands equal or excel in yields of lumber and other forest products the mature and overmature timber of the virgin forest. The quality of the lumber is not so high, since the individual trees are smaller; but the trees are young, thrifty, and small crowned, and there are more of them to the acre.

These well-stocked, even-aged stands afford the best index to the growth capacity of the southern Appalachian forest soils. Such stands have covered large areas (especially in the piedmont and foothill region of Virginia, eastern West Virginia, and Maryland) that were cut clean for charcoal wood during the era of the blast furnaces. They have come in throughout the region in smaller patches, particularly following heavy logging or fires that killed back the old stands completely or on land cleared for agriculture and later abandoned.

In order to determine the rate of growth and the yield of these well-stocked young stands of mixed hardwoods, 370 sample plots were measured [4] on many different qualities of site and in stands of different ages. The wood volumes in cords and board feet were graphically averaged and classified according to site, quality, and age. They are shown in Table 8. Of the five site classes shown, Sites I and II correspond to the moist-slope and cove forest, Sites IV and V to the dry-slope and ridge forest, and Site III to the poorer moist-slope or better dry-soil forest that constitutes the larger part of the mountain and plateau timberlands. The height of the taller (dominant) trees, shown in the third column, was used in connection with the age of the stand to determine the quality of the site, which is best expressed by height growth. The table also shows the average number of trees per acre, average diameter, and basal area [5] per acre for the trees down to and including the 6-inch and 10-inch diameter classes.

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[4] Most of these were measured in Maryland and Virginia by the U. S. Forest Service and the State forester of Maryland. Enough were measured later in the southern mountains to prove the general applicability of the yield tables when applied in accordance with the height of the dominant trees and the age of the stand.

[5] The basal area of a tree is its cross-section area at breast height, expressed in square feet. The total basal area per acre is a convenient measure for judging the density of stocking. It is computed from the tally of breast-high diameters.

TABLE 8.—*Average yields of well-stocked second-growth hardwood stands, on all sites* [1]

Site	Age	Height of average dominant trees	Yield per acre		Trees per acre		Average diameter breast high		Basal area per acre	
			6 inches and over d. b. h.	10 inches and over d. b. h.	6 inches and over d. b. h.	10 inches and over d. b. h.	6 inches and over	10 inches and over	6 inches and over d. b. h.	10 inches and over d. b. h.
	Years	*Feet*	*Cords* [2]	*Bd. ft.* [3]	*Number*	*Number*	*Inches*	*Inches*	*Sq. ft.*	*Sq. ft.*
Site I (best cove soils)	30	80	48	5,200	267	69	9.5	10.9	131	45
	40	93	64	14,300	240	142	10.9	12.0	156	112
	50	102	74	21,300	208	140	12.3	13.2	171	134
	60	110	82	27,300	175	136	13.6	14.2	177	149
	70	117	88	32,700	160	131	14.8	15.0	191	160
	80	122	93	37,600	148	126	15.6	15.7	197	170
Site II (moist slopes and coves)	30	67	32	1,400	255	29	8.4	10.6	99	18
	40	78	47	6,500	252	97	9.5	11.5	125	70
	50	86	57	12,200	226	119	10.7	12.3	140	98
	60	93	63	17,100	201	127	11.7	13.1	151	118
	70	99	69	21,300	182	130	12.7	13.7	160	133
	80	103	74	24,800	169	130	13.4	14.2	166	144
Site III (soils of intermediate quality)	30	54	21	400	235	13	7.4	10.4	70	8
	40	63	32	2,500	258	47	8.2	11.0	96	31
	50	70	40	5,700	248	90	9.1	11.5	112	65
	60	76	46	9,100	229	109	9.9	12.0	123	86
	70	81	51	12,300	212	121	10.7	12.5	132	103
	80	85	56	14,900	198	128	11.3	12.9	138	116
Site IV (better dry slopes and ridges)	30	40	8	-------	126	-------	6.5	-------	29	-------
	40	48	17	200	228	5	7.0	10.3	62	3
	50	54	24	900	253	22	7.7	10.9	81	14
	60	59	30	2,700	259	54	8.2	11.2	96	37
	70	63	34	5,100	251	89	8.8	11.6	107	65
	80	66	38	7,200	238	111	9.3	11.8	113	84
Site V (poorer dry slopes and ridges)	30	28	1	-------	41	-------	6.0	-------	8	-------
	40	33	6	-------	140	-------	6.2	-------	29	-------
	50	38	12	-------	233	-------	6.5	-------	53	-------
	60	42	16	50	284	1	6.8	10.2	71	1
	70	45	20	700	297	32	7.2	10.5	84	20
	80	47	23	1,700	288	61	7.6	10.7	92	38

[1] From tables prepared by W. D. Sterrett and the author from records of more than 350 stands of even-aged mixed hardwoods measured by W. W. Ashe, of the Forest Service, F. W. Besley, State forester of Maryland, and others. All timber scaled as sound and straight. The cord volumes were converted from cubic feet by means of a factor of 90 cubic feet of solid wood per cord of 128 stacked cubic feet

[2] One hundred and twenty-eight cubic feet as stacked.

[3] Scribner Decimal C.

The average yield of 80-year-old second-growth hardwoods indicated in Table 8 amounts to over 37,000 board feet per acre on the best sites (Site I) and to nearly 15,000 board feet on average land (Site III). In the poorest situations (Site V) it falls as low as 1,700 board feet per acre. Under treatment to be discussed later, the quality as well as the quantity of the yield can be increased in second-growth stands, and if allowed to reach the age of the virgin timber there is no reason why equally valuable lumber can not be raised, and in larger quantities.

The table also brings out strikingly the relation of height growth to site quality, which has been previously referred to, and the part played by the height of the timber in determining its yield. The great difference in growth capacity between the good and poor sites which is shown in Table 8 is still further brought out in Table 9. This table, compiled from Table 8, shows the average yearly growth per acre in cords and board feet.

TABLE 9.—*Average annual growth per acre of well-stocked second-growth hardwoods, in cords and board feet.* (*Computed from Table 8*)

IN CORDS, TREES 6+INCHES D. B. H.

Age (years)	Site I	Site II	Site III	Site IV	Site V
30	[1] 1.60	1.07	0.70	0.27	0.03
40	1.60	[1] 1.18	.80	.42	.15
50	1.48	1.14	[1] .80	.48	.24
60	1.37	1.05	.77	[1] .50	.27
70	1.26	.99	.73	.49	.29
80	1.16	.92	.70	.48	[1] .29

IN BOARD FEET, TREES 10+INCHES D. B. H.

30	173	47	13		
40	358	162	62	5	
50	426	244	114	18	
60	455	285	152	45	1
70	467	304	176	73	10
80	[1] 470	310	185	90	21

[1] Figures indicate peak of annual growth.

The figures in Table 9, marking the approximate ages at which the average annual growth is greatest, indicate that for trees 10 inches and over in diameter the growth in board feet reaches its culmination at 80 years for Site I. For other sites the growth reaches its maximum at ages not shown in the table—90 years for Site II, 100 years for Sites III and IV, and more than 100 years for Site V.

The vigor and freedom from decay of second-growth stands is contingent upon freedom from fire. A severe fire will not only set back the growth rate but, as will be shown later, will also kill small trees and open wounds in larger trees through which decay often becomes implanted. The damage is, of course, increased by each successive fire that burns in the woods.

FOREST-FIRE DAMAGE

Each year during the period 1923–1927 forest fires burned an area averaging 639,334 acres, or 2.7 per cent of the 23,468,000 acres of timberland under cooperative protection in the mountain and plateau regions of four southern Appalachian States.[6] The average number of fires each year was 2,322. Without doubt fires are more numerous and extensive in the unprotected areas for which statistics are less satisfactory. For the entire region the area burned annually during the 5-year period was probably in the neighborhood of 3 per cent.

The large areas thus damaged make fires by far the most destructive of all influences in the southern Appalachian forests. On reproducing areas the proportion of hardwood sprouts is increased (pl. 6, A) and the composition may be radically changed. In young stands more small trees than large ones are killed or injured. Fire therefore affects the future of the forest much more than it does its present condition. Stands are destructively thinned, leaving the land occupied by the older, often overmature, trees and by young trees crippled by wounds and subsequent decay. The treatment of young

[6] Virginia, North Carolina, West Virginia, and Tennessee. Comparable statistics for those portions of the other States which lie within the territory covered by this report were not available for the 5-year period considered.

second-growth stands in which many of the trees have been injured is one of the most difficult problems of the region.

Forest fires in the southern Appalachians are usually surface fires that burn in the leaf litter. Their destructiveness is increased by accumulations of logging slash, especially of hemlock, pine, or spruce, and by the dry, fire-killed material, including standing dead timber, left after earlier fires. The occasional crown fires which kill entire hardwood forests to the ground occur during very dry seasons. Such fires burned at several places in the mountains during the exceptionally dry summer of 1925 and late spring of 1926. In May, 1926, a fire of this character in Burke, Avery, and Caldwell Counties, N. C., burned over an area of more than 6,000 acres, killing the forest and strewing the ground with fuel enough for another killing fire, should one be allowed to escape within the next 15 or 20 years. Such fires are, however, relatively infrequent and may actually do less damage in the hardwood forests than the ordinary fire which kills the smaller trees and damages many saplings and small poles.

Since the chief means of spread of the ordinary fire is the layer of fallen leaves on the ground beneath the trees, surface fires are most common in the fall after the leaf crop is partially down and in the spring when the winter rains have ceased and before the vegetation is far enough advanced to keep the forest floor from drying out. They are unusual in the active growing season and during the winter, occurring only in dry periods or when a great quantity of débris on the forest floor forms an unusual fire risk. For the southern part of the Appalachian region the active spring fire season begins about the middle of March and ends about the middle of May. The fall season lasts usually about eight weeks, from the middle of October. In the northern part of the region the fall fire season begins and ends earlier, and the spring season is shorter.

Fires are more often fatal to small than to large timber, but generally the greatest damage to the stand is found among the trees that are wounded but not killed. (Pl. 6, B.) Surface fires hot enough to kill all the small seedlings and sprouts will injure many of the smaller trees and even large thick-barked trees that have leaves or branches lodged against them.[7] Trees injured at the base usually do not die but continue to grow and occupy space. Many of them become infected, through the fire scars, with wood-rotting fungi. (Pl. 7, A.) The decay may sometimes be arrested, but it may also spread in the wood of the trunk, greatly reducing the quantity and value of the final product. Most of the decay found in hardwood stands throughout the Appalachian region is due to successive fires. (Pl. 6, C.) The trees thus crippled continue to spread their crowns and thus prevent the successful development of reproduction.

In addition to the killing and wounding of trees, fires cause a heavy loss in soil fertility by destroying the leaf litter. The annual deposit of leaf litter in a well-stocked hardwood forest (pl. 7, B) is

[7] A mathematical relation can be found between the size of the trees and the degree of kill or damage effected by a fire of given intensity in the hardwood forests. Tabulated records obtained by E. F. McCarthy, of the Appalachian Forest Experiment Station, on 311 acres distributed uniformly over 2,820 acres of burned forest in various parts of the Appalachian Mountain region show that any fire severe enough to kill 50 per cent of the 3-inch trees (regardless of species) will kill practically all the 1-inch trees, about 73 per cent of the 2-inch, 34 per cent of the 4-inch, 22 per cent of the 5-inch, 15 per cent of the 6-inch, 11 per cent of the 7-inch, 9 per cent of the 8-inch, and proportionately less of all the larger trees down to about 1 per cent of the 17-inch class.

in the neighborhood of 2 tons per acre (*32*). From the best data available it is estimated that this quantity of hardwood litter contains 25 to 35 pounds of nitrogen, 12 to 15 pounds of phosphoric acid, and 5 to 7 pounds of potash. Under normal forest conditions these nutritive elements will be slowly released through decomposition of the litter. When the litter is burned its mineral content is left behind as an ash which is quickly dissipated by leeching and washing. A new accumulation of leaf litter must be built up before the nutritive process of decay can again be effective. On south slopes, particularly, the accumulation of litter on a burned surface is a slow process. In the meantime the soil becomes compacted and washes. (Pl. 7, C.) The combined effect is to reduce its growth capacity. A marked change in growth conditions can often be noticed, as when a poor, slow-growing young stand develops, after fire, among better trees of a previous generation.

As a rule there is a loss of a long period of years before the soil, on exposed situations, can be restored to full growth capacity, and an even longer period before the damaged trees can be replaced by thrifty ones. A dry-site forest may thus be so badly deteriorated as to be a continuing liability to the owner.

Defoliation is a common type of injury by fire to young stands of second-growth pine. An example of such injury is furnished by the records of a permanent sample plot established by the Appalachian Forest Experiment Station in its experimental forest at Bent Creek, near Asheville, N. C. (*16*). This plot of a quarter acre was established in April, 1925, immediately after a severe fire. The stand on the quarter acre contained 514 shortleaf pines about 25 years old. At the end of the third year 133 of the 514 trees were dead, mostly from defoliation. This number represents 18 per cent of the cubic volume of the stand. Of all the trees that were totally defoliated, 43 per cent had died. Of 34 trees partially defoliated, 26 had lost from 61 to 80 per cent of their leaves, 7 from 41 to 60 per cent, and only 1 as little as 40 per cent.

As a result of the defoliation, the growth of the stand was materially retarded. Measurements of more than 20 per cent of the larger trees showed that the basal area of the stand increased about 12 per cent in the three years preceding the fire but only a little over 3 per cent in the three years following it. During these three years 12 of the larger trees formed no annual growth rings at all, 10 formed only 1 ring, and 9 only 2 rings.

Fires are the greatest hindrance to timber production in the southern Appalachians. First importance should be given to their prevention. Cut-over areas must be kept free from fire or they can not be expected to recover even a fair degree of productiveness. The destruction caused by fires extends beyond timber production and affects every other important use of the forest. Spring fires destroy the nests and eggs of birds and the young of game animals, while the water-storage value of forest soils, which is essential to the long life of reservoirs, is reduced by fires at any season. Furthermore, each fire leaves an accumulation of dead wood which increases the severity of any subsequent fire occurring before this dead wood decays. The practical elimination of fires would be by far the greatest step forward in the reconstruction of the southern Appalachian forests.

ESTABLISHMENT AND EARLY DEVELOPMENT OF STANDS

ON UNBURNED CUT-OVER LANDS

Abundant reproduction of seedlings and sprouts usually springs up on cut-over lands within a few years after a moderate or heavy logging. (Pl. 9.) Not only do most of the species reproduce well, but ordinarily the new growth contains seedlings which were present before the logging. Such advance reproduction shoots up rapidly when released by the cutting of the larger trees, and also produces sprouts if killed back by fire. Plentiful reproduction of desirable species is always present in the hardwood forest if a suitable number of seed-bearing trees of desirable kinds are left standing. Where such seed trees are deficient, some of the less desirable species are so prolific and of such rapid growth as to predominate in the stand, unless they are weeded out sufficiently to give the desirable species an opportunity to become established.

Next to fire, the greatest impediment to the establishment of reproduction is the presence of large and small trees left standing after logging. Their adverse effect upon the reproduction will increase as their crowns spread out. Where they consist of vigorous young trees of good species, they are, of course, usually to be preferred to the reproduction, but crooked or unsound trees are detrimental, and their removal will clear the way for a much better future stand.

The proportions of shaded and unshaded reproduction on representative cut-over areas are shown in Table 10. Only the larger reproduction, 0.5 to 3 inches d.b.h., is included. The smaller reproduction is of less promise on areas that have been cut over as long as those illustrated, since much of it will be shaded out by the larger seedlings and sprouts, as well as by the trees.

Table 10 illustrates the density of the natural reproduction that ordinarily springs up after cutting; in most cases planting would be both unnecessary and unpractical because of the intense competition for light and growing space that planted seedlings would have to meet. In the natural reproduction itself, more than half of the seedlings and sprouts are shaded by trees, shrubs, or larger reproduction and will probably never reach merchantable size.

TABLE 10.—*Shaded and unshaded reproduction*[1] *in cut-over but unburned hardwood forest*[2]

Forest type	Not shaded, per acre			Shaded, per acre		
	Desirable species	Less desirable species	All species	Desirable species	Less desirable species	All species
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Dry slope and ridge:						
Black oak-scarlet oak type	94	258	352	191	634	825
Chestnut oak type	135	312	447	121	399	520
Moist slope and cove:						
Cove hardwood type	103	191	294	115	261	376
Northern hardwood type	171	84	255	138	168	306
Chestnut type	114	350	464	155	803	958

[1] Includes only the larger seedlings and sprouts, from 0.5 to 3 inches d. b. h.

[2] Prepared from the records of the sample plots used for Tables 5 and 7. The numbers and areas of the plots measured in each forest type and the period since the last cutting are as shown in Table 5.

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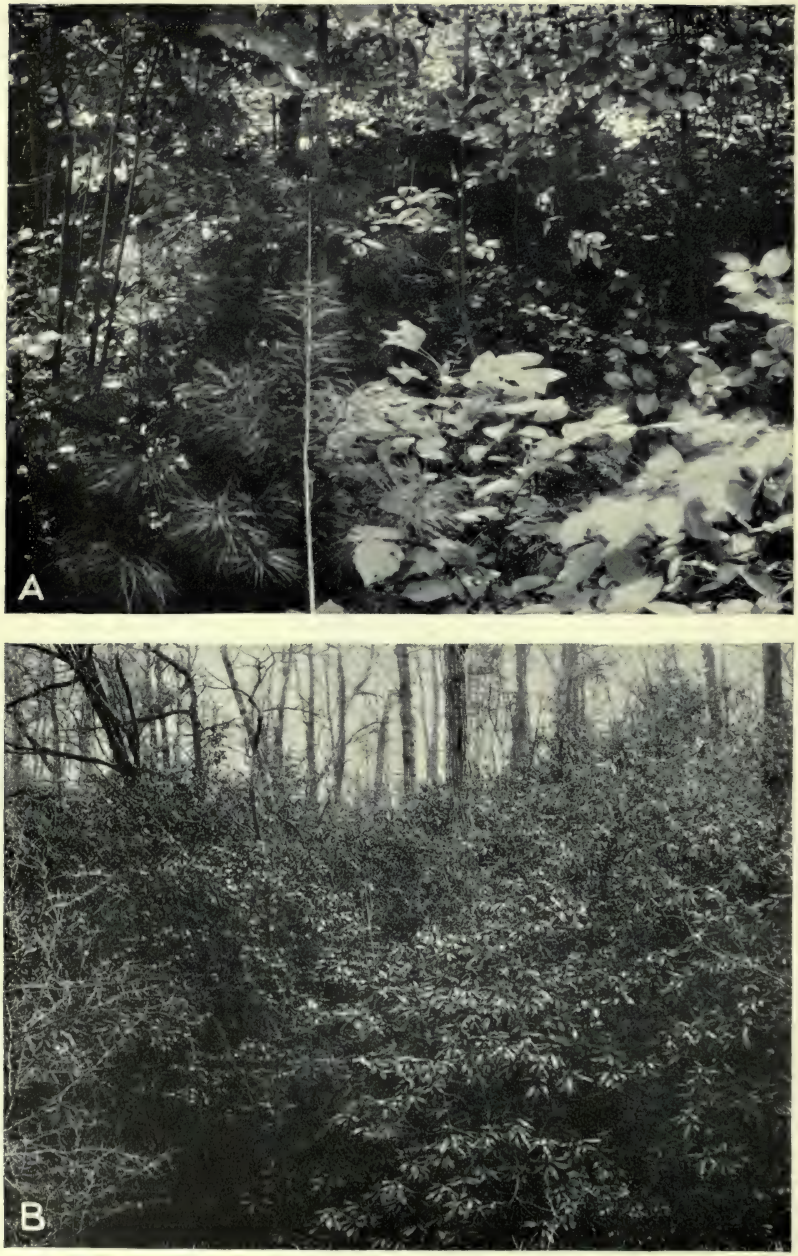
MIXED HARDWOOD REPRODUCTION WITH SECOND-GROWTH WHITE PINE IN BACKGROUND

A light thinning among the hardwoods is needed to release desirable species from competition with those less desirable.



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DENSE UNDERGROWTH IS AN EFFECTUAL BARRIER TO DESIRABLE REPRODUCTION

A, White pine and yellow poplar reproduction under a heavy cover, mostly of dogwood sprouts; B, dense undergrowth of rhododendron in an overcut hardwood forest.

In the spruce forest a considerable difference is to be noted in the conditions that affect reproduction. Seed years of spruce are infrequent, and fir does not bear heavy crops annually. After heavy cutting, even without subsequent fire, the seedlings are likely to be killed by the drying out of exposed duff, moss, or litter on which they start, by frost heaving, or by suppression under the shade of weeds, shrubs, and hardwood sprouts and seedlings.

AFTER FIRES ON CUT-OVER LANDS

Fires lower the value of the future stand by increasing the proportion of the poorer species and of sprouts. Although reproduction after fire may be heavy, its quality and promise are likely to be lower than on unburned areas. Exceptions to this may occur when severe fires, happening at times when desirable species have produced good seed crops, may greatly assist in establishing these species by clearing the ground of competing vegetation. Thus good stands of pine or yellow poplar of seedling origin are sometimes found on areas that have been severely burned. After such reproduction has become established, fires are disastrous.

The usual effect of fire, however, is illustrated for the hardwood forest in Table 11, which shows the amount and kind of reproduction the first season after a fall fire on dry and moist sites.

TABLE 11.—*Tree reproduction less than 0.6 inch d. b. h. in the first season following a severe fire in dry-site and moist-site forests* [1]

Species	Reproduction per acre in dry-slope and ridge forest			Reproduction per acre in moist-slope and cove forest		
	Seedlings	Sprouts and sprout clumps	Total	Seedlings	Sprouts and sprout clumps	Total
Desirable:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Yellow poplar		6	6	530	17	547
Chestnut oak	1	243	244		513	513
Red and white oaks					152	152
Birch [2]				8	8	16
Black locust	8	144	152		353	353
Yellow pines [3]	932		932	84		84
Total	941	393	1,334	622	1,043	1,665
Less desirable:						
Chestnut	1	498	499	8	749	757
Scarlet oak	1	251	252		126	126
Hickory		36	36		93	93
Red maple	1	235	236	329	657	986
Black gum		359	359		67	67
Sassafras		719	719	59	649	708
Sourwood		126	126		311	311
Dogwood		28	28		59	59
Total	3	2,252	2,255	396	2,711	3,107
Grand total	944	[4] 2,645	3,589	1,018	[4] 3,754	4,772

[1] Rock Creek, Unaka National Forest, Tenn. Burned in October, 1921. Examined in July, 1922.

[2] Mostly yellow birch, some sweet birch.

[3] Pitch, mountain, and shortleaf pines. In the dry-slope and ridge forest there were 41 single sprouts and 72 sprout clumps of pine per acre. These are not shown in the table as they are without any probable significance in the reproduction.

[4] On the dry site, single sprouts comprised 27 per cent and sprout clumps (tallied as units) 73 per cent of the sprout reproduction. On the moist site, these proportions were 41 and 59 per cent, respectively.

Single sprouts and sprout clumps on the burn cited in Table 11 make up 74 per cent of the reproduction on the dry site and 79 per cent on the moist site, and these proportions would have been much greater if all the sprouts in the clumps had been counted. Furthermore, the less desirable species have produced two or three times as many sprouts on the moist site as the more desirable. The sprouts alone are more than ample to restock the area, and because of the early growth impulse of sprouts the survival of the seedlings is endangered. This is especially true with the seedlings of the yellow pines, whose early growth is very slow. The more rapid-growing species, such as yellow poplar, will usually find space for growth in chance openings among the sprouts. A rapid decrease in the number of living trees per acre is to be expected as the stand grows. Table 8 shows, for example, that 40-year-old stands of well-stocked second growth on the better dry slopes and ridges will contain about 228 trees per acre that are 6 inches d. b. h. and over, or less than 6.5 per cent of the initial stand of sprouts and seedlings shown for this site in Table 11. The corresponding percentage for the moist slope and cove site is less than 5.5 per cent.

The effect of fire upon reproduction in the spruce forest of North Carolina is illustrated in Table 12 and Figure 6. The uncut spruce forest is nearly fireproof because of the heavy shade and consequent dampness of the forest floor. When cut over, however, the fire risk is very great, and a large part of the area formerly covered by this forest now has only scattered trees of spruce and fir. The table illustrates the negligible proportion of spruce, fir, and hemlock reproduction and the preponderance of yellow birch and of worthless small trees and shrubs that are characteristic of severe burns in the spruce forest.

TABLE 12.—*Reproduction per acre, less than 1 inch d. b. h., on burned and unburned cut-over areas in the spruce forest, by species*

Species	On unburned area [1]	On burned area [2]
Red spruce	88	16
Southern balsam fir	555	7
Hemlock	27	1
Yellow birch	715	4,197
Small tree species and tall shrubs	[3] 5,418	[4] 23,789
Total	6,803	28,010

[1] Cut in 1918–19, examined in 1922 (0.9 acre), Hornbuckle Creek, Jackson County, N. C. The original stand contained 76 spruce and fir and 3 yellow birch trees, per acre, over 12 inches in diameter breast high; of these, all the spruce and fir were cut. Present stand contains 458 spruce and fir, and 4 yellow birch trees per acre between 1 and 12 inches in diameter.

[2] Cut in 1917, burned in 1918 (fall), examined in 1922 (3 acres), West Fork, Pigeon River, Haywood County, N. C. The original stand contained 93 spruce and fir and 4 yellow birch trees, per acre, over 12 inches in diameter breast high; of these, all the spruce and fir and all but 1 of the yellow birch trees were removed. Present stand contains 2 fir trees and 2 yellow birch trees per acre between 1 and 12 inches in diameter.

[3] Rhododendron, 12 per cent; pin cherry, 69 per cent.

[4] Rhododendron, 10 per cent; pin cherry, 75 per cent.

In the spruce forest the characteristic cover after fire is of raspberry, blackberry, and other bushes, into which advances later a practically worthless stand of pin cherry, or of yellow birch seedlings for whose rapid growth or symmetrical development soil and exposure

are often unfavorable. Often burned-over areas are seized by rhododendron or laurel, producing the so-called "ivy slicks." The only way to restock spruce burns with spruce, fir, or other suitable softwoods is by planting, which should be done immediately after the burning, so as to avoid as far as possible the losses from competition with the shrubby vegetation which will quickly appear.

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FIGURE 6.—The cut-over and burned spruce forest as it appears a few years after the burn—no sign of spruce or fir reproduction and no seed trees left to supply it. (Mount Mitchell, N. C.)

SEEDLING AND SPROUT REPRODUCTION

The reproduction on cut-over hardwood lands in the southern Appalachian region is generally a mixture of seedlings and sprouts. Under suitable conditions most of the hardwoods reproduce well in both ways. The conifers—pines, spruce, fir, hemlock, and red cedar—reproduce only by seed.[8] The different tree species in the forest have distinct individual characteristics of seed production and germination, capacity to produce successful sprouts, and early growth rate of seedlings and sprouts, and a knowledge of these characteristics can be utilized in logging to control the composition and value of the future stand.

As a rule, seedlings make better trees than sprouts. Sprouts at first grow more rapidly than seedlings, since they can draw on the root systems of the parent trees. They may outgrow seedlings for a few years or for several decades, but except in the case of chestnut and perhaps basswood they do not long maintain their superior growth and do not reach the large sizes attained by trees that have grown direct from the seed. Seedling trees also are likely to be healthier than sprouts, which frequently become infected with diseases present in the stumps or roots from which they have sprung.

[8] Shortleaf pine, as has already been noted, reproduces also by sprout, but not well enough to make this means practical under ordinary conditions.

Sprout growth exhibits a vigor in inverse ratio to the size of the stump from which the sprout originates. Seedling sprouts (single sprouts from small stumps of an inch or less in diameter) are practically as good as seedlings, over which they have the advantage of the early growth impulse. As a rule, sprouts from trees large enough to be cut for saw logs are weak and temporary. Of all the southern Appalachian species, basswood and chestnut are the only ones that commonly produce large timber from sprouts grown from the stumps of trees of saw-log size. Chestnut, or course, is out of consideration because of the blight, and basswood is not very abundant. Among the oaks, chestnut oak is the most prolific and persistent sprouter. The sprouting capacity of most species diminishes with successive cuttings.

In their capacity to reproduce by seed the tree species differ quite widely. The good seed crops borne by many of them are a source of food to rodents, birds, and insects, and only a small part of the seed produced escapes destruction. A few—notably basswood, holly, hemlock, and cucumber magnolia—often fail to reproduce (for reasons not as yet well understood) even when the seed supply is plentiful. Of the oaks, white oak and red oak are frequently deficient in seedling reproduction, but chestnut oak is usually prolific. Yellow poplar, also, is an excellent reproducer under favorable conditions of soil and moisture. Among the best, however, are some of the least desirable species, and this fact emphasizes the advantage of leaving seed trees of the better species in order to maintain or improve the quality of the forest composition. For all species that do not sprout well, seed trees are the best guarantee of successful reproduction. For those that do produce vigorous sprouts, seed trees are desirable as a means of rejuvenating the stand with a more lasting form of growth.

The efficiency of seed trees is lowered by the losses to which seeds may be subject in the forest. Seed destruction by squirrels, chipmunks, mice, birds, and insects is particularly important for the heavy-seeded species. From counts of acorns made under the crowns of 37 seed-producing trees of chestnut, white, black, and red oaks, Korstian (*34*) found that of a crop averaging 3,500 acorns per tree, 98 per cent were destroyed by animals or insects, or failed to germinate for other reasons. There is evidence that the seed of other valuable species is subject to similar heavy losses.

Other losses result from forest-floor conditions unfavorable to the germination of seed or the establishment of seedlings. It was found by Korstian that acorns which germinate on excessively compact soil are unable to take root. Two hundred acorns each, of red, black, white, and chestnut oaks, were put on a bare soil surface and covered 2 inches deep with hardwood-leaf litter. The same number for each species were similarly placed but without litter cover. On the bare areas an entire failure of seedling establishment resulted, whereas on the soil protected by leaf litter the survival was from 64 to 93.5 per cent. Only when the acorns are buried in mineral soil by heavy rains does there appear to be much chance of seedling establishment without a cover of leaf litter.

Yellow poplar, on the other hand, requires a mineral soil for germination, though soil moisture is necessary. Hemlock, sugar maple,

beech, birch, spruce, and fir will germinate in decomposed organic material, extending their roots through it to the mineral soil. Organic material in the soil has a stimulating effect upon reproduction of trees of all kinds; the vigorous growth of young stands on newly cleared sites is due to the large amount of humus in the forest soil (*63*).

When seed production is heavy, even though losses are as great as those above noted, there may be some germination of seedlings of desirable kinds; but the reproduction that results is usually too scanty to be of much promise for the future stand. Losses are sure to occur after germination, owing to the severe competition to which the reproduction is subjected. The especially desirable kinds should therefore be amply represented, and this can best be insured by leaving a considerable number of well-chosen seed trees.

Sprout reproduction is especially characteristic of burned cut-over lands (pl. 6, A) as brought out in Table 11; but even on unburned areas sprouts often outnumber seedlings. This is shown in Table 13, based on the same representative areas that furnished the data for Tables 5, 7, and 10. Sprouts form 38 to 53 per cent of the total unshaded reproduction in the several types represented, and far outnumber the seedlings of the desirable species. If the reproduction should be killed back by fire the ensuing growth would consist very largely of sprouts, as in the cases already discussed.

TABLE 13.—*Comparison of sprouts and seedlings among unshaded reproduction in unburned cut-over hardwood forest* [1]

Forest type	Seedlings per acre		Sprouts per acre		Total reproduction per acre
	Desirable species	Less desirable species	Desirable species	Less desirable species	
	Number	*Number*	*Number*	*Number*	*Number*
Dry slope and ridge:					
Black oak-scarlet oak type	79	118	15	140	352
Chestnut oak type	101	140	34	172	447
Moist slope and cove:					
Cove hardwood type	85	96	18	95	294
Northern hardwood type	53	68	118	16	255
Chestnut type	89	189	25	161	464

[1] Prepared from the records of the sample plots used for Tables 5, 7, and 10. The numbers and areas of the plots measured in each forest type, and the period since the last cutting, are shown in Table 5. The figures are for reproduction from 0.5 to 3 inches d.b.h. Since single sprouts from very small stumps quickly assume the characteristics of seedlings, all such were tallied as seedlings.

EFFECT OF COMPETITION IN YOUNG STANDS

Sprouts and seedlings of the less desirable species are commonly a serious menace to the reproduction of better species. In the older cuttings dogwood, sourwood, and other inferior small trees are frequently found to have outgrown better species and to form the greater part of the crown cover. (Pl. 10, A.) The time to prevent this is while the reproduction is small enough to be easily cut or broken back and before there has been much loss among the desirable species. What may be accomplished is illustrated by a weeding experiment now being conducted by the Appalachian Forest Experiment Station near Lookingglass Rock, Pisgah National Forest, N. C. A heavy reproduction of yellow poplar that started

after a burn in May, 1916, soon became overgrown by a dense cover of sumac and sprouts of inferior trees. In 1924 this cover was 10 to 25 feet high, while the average height of the poplars was only 2 or 3 feet; they were weak and spindling, and evidently suffering badly from the dense shade and root competition of the overtopping chestnut, silverbell, sumac, and other inferior species. About two-thirds of the stand of inferior species was cut back in 1924 on a sample area of 1 acre. Four years later it was found that the number of yellow poplars over 0.5 inch d. b. h. had increased by nearly 500 per cent, while the increase in the number of inferior species was less than 30 per cent. The poplars had gained in vigor and, on an average, were 3.8 feet taller than those on an adjacent sample plot that had been left untreated for comparison. There is now little doubt that yellow poplar will predominate in the future stand on the weeded area. On the unweeded area practically all of the poplar will be killed out by the inferior species that monopolize the crown cover.

Rhododendron and laurel often cover the ground with a dense shade underneath the forest crown cover (pl. 10, B) or outside of the forest, the laurel commonly on high slopes and ridges. Outside of the forest, these "ivy slicks" appear to have fast hold of the ground, preventing the development of tree seedlings. Presumably they were present under the original forest, which gave way to them through inability to renew itself, for under tree shade laurel and rhododendron thickets will entirely prevent tree reproduction. Considerable areas of otherwise good forest soil support only scattered defective old-growth timber, left after logging, with practically no undergrowth except these tall, heavy-foliaged evergreen shrubs.

Rhododendron and laurel usually grow in clumps or sprouts that spread out widely from the center. When cut back, quite a number of years will elapse before the clumps again come together. This gives time for the establishment of tree seedlings between the clumps. Numerous observations indicate that seedlings of poplar and other hardwood species have little trouble in keeping ahead of laurel and rhododendron sprouts if given an equal chance.

A somewhat similar condition exists on dry, burned areas where various huckleberries and other shrubs form a dense ground cover 4 or 5 feet high under thin stands of scarlet oak, pines, and other dry-site species left after logging. The shade is not so dense, but with the dryness of the soil, which accentuates competition for moisture, a combination very unfavorable to tree reproduction is set up.

In thin-soiled spruce forest, heavy logging may cause the death of rhododendron through the drying out of the soil. This frees the soil of the dense cover but adds to the inflammable accumulation of slash and litter that makes cut-over spruce forest the most dangerous fire risk of all the southern Appalachian forests. The drying of the soil when the cover is removed may also inhibit spruce and fir reproduction, except in moist spots between the rocks.

A common cause of injury in young second-growth stands is the presence of vines, particularly grapevines. These smother the crowns and bend small trees over by their weight, often damaging or destroying the greater part of a sapling stand. The obvious remedy is to sever the vines, where the damage has not already gone too far for recovery.

FOREST-INSECT DAMAGE[9]

Damage by forest insects to standing timber and to forest products represents an appreciable annual drain upon the timber supply of the southern Appalachians. While it has not been possible to make sufficient studies to evaluate these losses accurately, enough information has been obtained to show that insects are an important factor, as well as fire and chestnut blight, in directly affecting the continuous timber production of the region.

The greater part of this damage is caused by bark beetles which destroy living trees and by boring insects which affect the quality of the wood of trees. Seeds and seedlings also sustain considerable losses. Additional injury results from defects in the felled product. This may vary from a slight degrade to a total loss of the material for the purpose for which it was intended. Damage to lumber and to seasoned finished products is high because of the money represented in materials and in the labor expended upon them.

INSECTS AFFECTING LIVING TREES

Some of the more important insects which affect living trees, either causing death or defects in the parts which furnish commercial products, are the southern pine beetle, *Dendroctonus frontalis* Zimm., which kills all species of pine within its range; the chestnut timber worm, *Melittomma sericeum* Harris, an insect which causes "shot wormhole" defects in almost every chestnut tree; the oak timber worm, *Eupsalis minuta* Drury, which is responsible for the same type of defect in oaks, particularly in northern red and chestnut oaks; the Columbian timber beetle, *Corthylus columbianus* Hopk., which makes defects known as spot wormholes in white and chestnut oaks; the locust borer, *Cyllene robiniae* Forst., which infests practically all young reproduction up to the time it has reached a diameter of 6 inches, unless protected by shade; and the hickory bark beetle, *Scolytus quadrispinosus* Say, which is attracted to hickory trees that have become weakened by such agencies as drought, fire, or lightning.

Southern pine beetle epidemics are the cause of serious periodic losses to pines in the southeastern section of the United States. It has been estimated that the value of timber killed by this beetle alone during the past 40 years, based on present stumpage values, would amount to-day to about $50,000,000. A considerable portion of the pine killed during this time has been in the southern Appalachian region, particularly in the States of West Virginia, Virginia, North Carolina, and Tennessee. Although shortleaf and pitch pines are probably most susceptible to attack, other species, including white pine, have been killed over large areas, especially in West Virginia.

Southern pine beetle outbreaks are correlated with marked deficiencies in rainfall. Since the year 1922 many such "killings" have been found within national forests and State parks in western North Carolina and eastern Tennessee. In the drought years 1922, 1925, 1927, and 1930 beetles were abundant in these areas. During the record-breaking drought of 1930 what is believed to be one of the

[9] Prepared by R. A. St. George, Associate Entomologist, Division of Forest Insects, Bureau of Entomology.

largest epidemics since 1911 was located in the Smoky Mountains in the vicinity of the proposed new park area. As a result of these group killings, this beetle has been responsible for the change from pure pine to mixed pine-hardwood stands.

This beetle has also been attracted to recently burned areas. This was true in the case of three spring fires which occurred in pine stands located on the land of, or adjacent to, the Pisgah National Forest.

It is quite well known that summer cutting of pine creates conditions attractive to this beetle. In the Pisgah Forest it was found that this beetle followed a logging operation over a period of four or five years, from one mill site to another, infesting trees in the vicinity of the cuttings and of the mill. In addition the cull logs left in the woods and large tops down to a diameter of 4 inches served as breeding places.

The chestnut timber worm, in addition to causing defects which result in a degrade in lumber, also weakens the tree sufficiently to enable other less aggressive wood borers, as well as fungi, to establish themselves successfully. During a recent study [10] of Appalachian hardwoods to obtain information on small sawmill operations, it was ascertained that 82 per cent of the primary and 11 per cent of the secondary defects (shot wormholes) in chestnut logs and lumber were caused by this insect. Results of entomological investigations, conducted in cooperation with the Forest Service in this study, indicated that 96.2 per cent of the sound wormy grade of lumber was affected by this beetle, which resulted in a 50.6 per cent loss for the grade. The work of this insect is largely confined to parts of the tree which have been injured or weakened in some way.

The oak timber worm often causes considerable damage to large, mature, or overmature white oak trees. These defects (shot wormholes) in wood put to special use, such as for cooperage purposes, are often so extensive that the wood is rendered useless. This is especially true of some of the white oak removed in West Virginia. The northern red and chestnut oaks in the Pisgah and Shenandoah National Forests also contained some of these defects.

The Columbian timber beetle not only causes damage by making pinhole defects (spot wormholes) in logs and lumber but also has a black stain associated with it which discolors the wood for 2 to 3 inches each side of the gallery in oak. In yellow poplar these streaks are sometimes 5 or 6 feet long, and then the wood is designated as "calico poplar." In the above-mentioned cooperative study by the Bureau of Entomology the work of this beetle was found in 20.5 per cent of the chestnut oak and in 3.7 per cent of the white oak logs.

The locust borer is an insect which presents difficulties to the production of good-quality black locust in the southern Appalachians. It attacks practically all saplings up to post size, when grown in the open without adequate protection of shade. In some plantations this injury is so extensive that it makes the production of this species on a commercial scale unpractical. In such cases the wormholes are so numerous from repeated attacks, year after year, that the weakened

[10] GARVER, R. D., and MILLER, R. SMALL SAWMILL UTILIZATION OF APPALACHIAN HARDWOODS. PART I. LUMBER . . . U. S. Dept. Agr., Forest Service . . . p. 81. December, 1929. [Mimeographed.]

stems readily blow over in a windstorm. While this condition has not been observed in this section, yet about the only trees free from injury are those that have come up in a thick stand or under cover of other species.

Hickory bark beetle outbreaks are not frequent. However, whenever trees are weakened by conditions of drought or fire, this beetle is often attracted and trees are killed (*50*). Hickory trees weakened by fire during the spring of 1927 in the Pisgah National Forest were attacked by this insect and died.

INSECTS AFFECTING FOREST PRODUCTS

Recent estimates by the Bureau of Entomology of insect damage (*72, p. 17*) to all classes of forest products, not including replacements, has placed this loss at $50,000,000 for the entire country. In an earlier part of this bulletin it was estimated that the southern Appalachians produced about 6,000,000,000 board feet of products annually. If the percentages of loss in each class of products, estimated for the country as a whole, were applied to this figure and evaluated accordingly, the annual loss to forest products for this region would amount to $670,750. These figures were based on a loss of 2 per cent each for lumber, fuel wood, and railroad ties, and 5 per cent each for pulpwood, mine timbers, and cooperage. It is realized that these figures are only roughly approximate, but they indicate that there is probably a greater annual loss to forest products than might be suspected.

Injury to forest products is caused by beetles and "grubs" of certain wood-boring insects which cause pinhole and wormhole ("grub hole") defects in logs and lumber. Seasoned lumber and finished wood products are also damaged and sometimes completely destroyed by other insects known as powder-post beetles, which are capable of reducing wood to a powdery mass. Construction timbers and other wood materials utilized in buildings, bridges, railroad operations, and mining and rustic work are often infested by beetles or grubs of other insects and by termites. Stored oak, chestnut, and hemlock bark used for tanning purposes is, under certain conditions, damaged by insects. These insects work in the inner bark, reducing it to a powdery mass.

THE CHESTNUT BLIGHT

The accompanying map (fig. 7), prepared by the Office of Forest Pathology, Bureau of Plant Industry, shows for 1930 the status of the chestnut blight, which has already spread throughout the range of chestnut in the southern Appalachian region. In all the chestnut-producing counties of Virginia 80 per cent or more of the chestnut trees are infected. Forty-five counties of West Virginia, 22 of North Carolina, 3 of South Carolina, 10 of Georgia, and 7 of Tennessee are in the same condition of infection. In all the remaining 87 counties with extensive chestnut growth in these States and in Kentucky, from 30 to 79 per cent of the chestnut trees are infected. Forest pathologists who have studied the spread of the blight since its discovery in New York City in 1904 believe that by

1935 nine-tenths of the counties in the southern Appalachian range of chestnut will be 80 to 100 per cent infected (*26*).

Investigations by the Office of Forest Pathology (*25*, *25a*) have shown that once the disease has established itself in a stand its progress is fairly well defined and the future degree of infection, mortality, and consequent deterioration can be estimated quite closely.

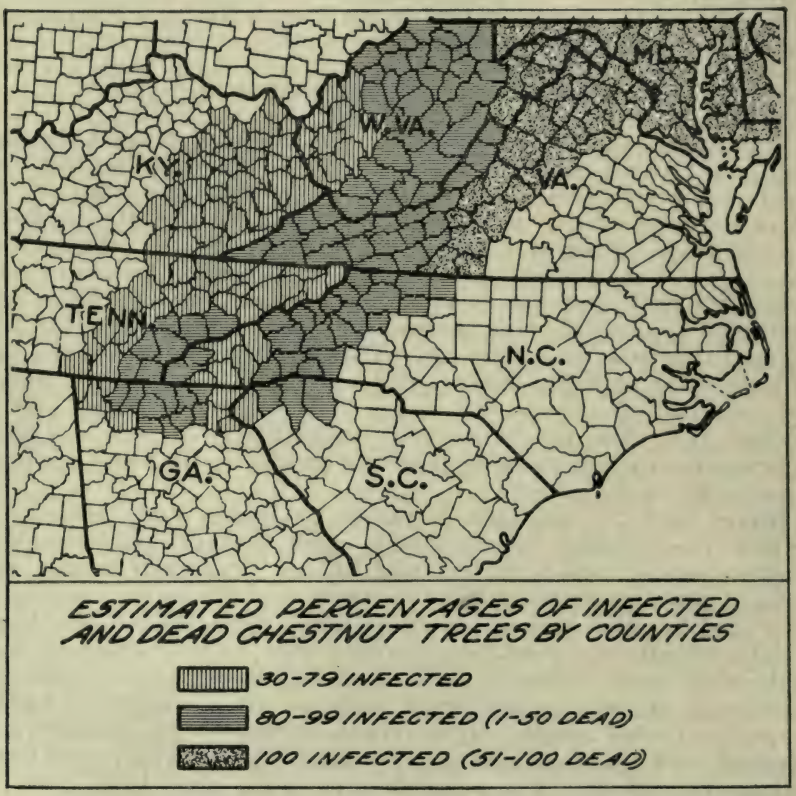

FIGURE 7.—Distribution of chestnut blight in the southern Appalachians

Table 14 presents the general trend of increase in the percentage of infected and dead trees as found on a number of areas in Virginia and Maryland.

TABLE 14.—*Progress of infection and mortality by chestnut blight following establishment of the disease, Virginia and Maryland, 1927* [1]

Period after infection of 1 per cent	Trees infected	Trees killed	Period after infection of 1 per cent	Trees infected	Trees killed	Period after infection of 1 per cent	Trees infected	Trees killed
Years	*Per cent*	*Per cent*	*Years*	*Per cent*	*Per cent*	*Years*	*Per cent*	*Per cent*
1	3		6	80	2	11	100	75
2	10		7	90	5	12	100	85
3	20		8	95	15	13	100	90
4	40		9	99	30	14	100	95
5	60		10	100	55			

[1] As presented in (*25*).

The increase in infection of about 10 per cent and in mortality up to 95 per cent appears to follow a definite order of progression. Thus the owner of chestnut timber who finds that 20 per cent of the trees are infected can be reasonably certain that after three years the trees will begin to die and that within seven years the stand will be completely infected and half the trees dead. With this knowledge the owners of considerable tracts of chestnut containing different degrees of infection can systematize the salvage operations. The owner of the 20 per cent infected stand can afford to wait three years without fear of serious loss, and to concentrate the salvage on the stands in which the disease has reached the most advanced stage. This delay may permit the owner of a recently infected stand to postpone or prolong the salvage so as to await a more favorable market.

Twenty-five years ago, before the significance of the blight then newly discovered in the North was realized, chestnut was just on the threshold of economic importance. After that it grew steadily in estimation and now combines more uses than any other tree in the southern Appalachian Mountains. It is one of the most widely distributed species, occurring not only in a distinct chestnut type, usually on north exposures, but also as an important component of the forest in coves and on lower slopes, dry slopes, and even ridges, up to an altitude of 5,000 feet. Since it is one of the most rapid-growing species and exceeds all others in its capacity to reproduce abundantly and well by sprouts, it apparently had the greatest promise for forest management.

In spite of the heavy loss through the blight, chestnut still is the most abundant timber tree in the southern Appalachian Mountains. According to Table 3 it comprises 13 per cent of the total stand of national-forest saw timber. Some of the individual national forests, however, report much larger percentages. According to the estimates for the Pisgah and Unaka National Forests, chestnut forms 27 per cent of the total saw-timber stand. Of the stand available for products other than saw timber, chestnut forms an even larger proportion. In the total cordwood stand reported by the national forests (Table 4) chestnut tanning-extract wood made up over 64 per cent; for the Nantahala and Natural Bridge Natural Forests the proportion was 97 per cent. Chestnut figured also in the estimates of fuel wood, railroad ties, and posts and formed practically the entire estimated number of poles. A rough estimate of chestnut extract wood made in 1925 placed the total stand in the southern Appalachian region at 33,700,000 cords, two-thirds of which was available to existing tanning-extract plants (*24*).

All research to find means for conquering the blight or arresting its spread has thus far proved fruitless. Although it is possible that in some way enough of the chestnut will be saved to permit its gradual return, the immediate concern of timberland owners is to salvage their present stands of chestnut in time to prevent total loss through death and decay. Unfortunately for the salvage of chestnut, the present demand for chestnut products is not nearly large enough to justify the hope that the bulk of the stand can be economically utilized. The disease is acting too rapidly and the distances from which much of the wood must be brought are too great for the operation to be profitable. Where chestnut will pay its way

out of the woods its early removal is distinctly desirable, both for the profit on the material that would otherwise be lost and to avoid delay in the regeneration of the forest.

For a year or possibly two after death a blight-killed chestnut tree will furnish just as good wood as any cut from a live tree. If the tree is left standing longer than two years the sapwood begins to decay, but the heartwood still remains sound and suitable for a great number of sawed products. In the next stage of deterioration the heartwood begins to dry out and consequently to check. Lastly, if within about six years the tree is not cut and taken from the woods the heartwood becomes infected with decay, which destroys its usefulness for practically all purposes except extract wood and fuel.

Table 15, prepared by the Forest Products Laboratory, lists the main uses for which blight-killed chestnut is suitable, according to the state of the wood when cut. Owners of chestnut timber would do well to consider possible markets in the order in which the products are grouped in the table. Manufacturers or users of these products should give chestnut all possible consideration, for their demands during the next 15 years will determine how much of this valuable wood can be saved from total loss.

TABLE 15.—*Utilization guide for blight-killed chestnut*

Period after death of tree	State of wood when cut	Best uses
Up to 2 years	Sapwood and heartwood sound	Poles and mine timbers. Highway and railway fence posts. Railroad ties.
2 to 4 years	Sapwood decayed but heartwood sound and unchecked.	Boxes and crates. Core stock. Slack cooperage. Yard lumber and planing-mill products. Millwork. Furniture and cabinet work. Coffins and caskets. Woodenware novelties.
4 to 6 years	Sapwood decayed; heartwood checked, but sound.	Rough construction. Farm fence posts. Tannin wood. Pulpwood.
6 years and after	Heartwood badly checked and infected with decay.	Fuel wood.

A large majority of commercial organizations prefer living chestnut to dead for their particular uses. For poles some companies accept only living trees, while others take dead chestnut as well. The larger purchasers will not accept chestnut poles showing blight cankers or decayed sapwood; other companies specify that the portions to go below ground shall be free from sapwood rot or cankers. For extract wood chestnut trees can be used for many years after they have been killed, although after about four years there is some loss in volume through the decay of sapwood. Studies by the Office of Forest Pathology, Bureau of Plant Industry, in cooperation with extract companies, indicate that the loss in tannin content is not excessive even in trees that have been dead 20 or 30 years (*45*).

The most profitable use for chestnut trees that meet size and form requirements is for poles. Trees between 10 and 17 inches d. b. h., capable of supplying poles 25 to 65 feet long, are usable if they comply with the specifications as to straightness, taper, and defects.

Only a small portion of the total stand, therefore, is usable for poles, but suitable trees are generally worth at least twice as much for poles as for saw logs (*48*). The stands that will produce the greatest percentage of poles are usually sprout stands that followed cuttings made 25 to 75 years ago. Blight-killed trees should be cut while green or as soon after death as possible in order to avoid loss in felling, since dead timber breaks more easily than green. As sound wood is required for poles the trees should not be left standing more than one or two years.

The loss of chestnut will greatly change the composition of the forest. A study of the character and effectiveness of natural replacement of blight-killed chestnut in the earlier-infected chestnut stands of the Northeast (*35*, *36*) indicates that the natural replacement of chestnut with desirable species is rapidly taking place. The new growth as it has appeared in the Northeast is largely red oak, white oak, chestnut oak, black oak, and scarlet oak, associated with hickory, white ash, sugar maple, and other valuable species. In addition to this, the species associated with the chestnut in the original stand gain greater growing space and a consequent stimulation in growth. The crowns of these trees are effectively closing the openings left by the death of the chestnut. The remaining stand has responded to the increased light and space with increased growth, ranging from 26 per cent in white oak to 63 per cent in red oak. Although this increased growth rate is smaller than was the growth rate of the chestnut, the stands, both young and old growth, are well on the way to recovery.

In the southern Appalachians much the same result can be expected. Of the many tree species with which chestnut associates on different sites, the majority are good reproducers, and a number are of rapid growth and considerable intrinsic value. Studies of chestnut replacement are now being conducted by the Appalachian Forest Experiment Station by means of permanent sample plots, and the indications are that the natural replacement of chestnut by other species in the South should be equal to that in the North, if not more effective (*33*). What these species will be, of course, depends upon the composition of the stands on the different sites and the aggressiveness of the different species in reproducing. A preliminary study made in 1920 by E. R. Hodson, of the Forest Service, resulted in the conclusion that there is in general sufficient advance growth of desirable species to restock the stands. On some unfavorable sites, however, the advance growth is inadequate, and where this condition is complicated by dense underbrush there is danger that the establishment of desirable species will be delayed for a long time.

The opinion has occasionally been expressed (*30*) that later generations of chestnut sprouts from the stumps of cut or killed trees are resisting the blight and may finally become immune or escape infection. If this should be the case, it is possible that here and there some of the chestnut may survive the disease so that the species will not be entirely exterminated.

A review of the chestnut-blight situation (*23*) suggests the following conclusions:

Satisfactory replacement with other species is generally to be expected.

Successive, short-lived generations of sprouts from blight-killed chestnut, with their tendency to spread out and monopolize growing space, endanger the development of other hardwood reproduction. This danger is augmented in mixed stands by the growth of shrubs and the shade from living trees. The tendency of the crowns of "hold overs" to expand and fill openings left by the death of the chestnut increases the shade still further. In the southern Appalachians the problem is rendered acute by the fact that some of the most desirable tree species are not able to endure prolonged shading.

Timber owners should take any profitable opportunity that arises to dispose of chestnut, preferably in advance of the blight.

ECONOMY IN RESERVING SMALL TREES FOR GROWTH

Lumbermen know in a general way that small logs and trees are more costly to cut and handle, and that they saw out a poorer quality of lumber than large ones, but the relative profit or loss involved in handling different sizes of trees is rarely given much consideration. Operations are constantly encountered in which trees too small to pay their way out of the woods are cut and manufactured into lumber. This constitutes both a direct financial loss to the operator and a reduction in the value of the stand for future cutting. As a factor in continuous timber production, young trees on the verge of commercial value are the very ones which it is most important to leave in the stand. To cut them at a loss is thus doubly uneconomic. Even when large enough to yield a slight immediate profit to the operator, their prospective value to the timberland owner will generally warrant leaving them for a future cut if they are straight and sound.

Tables 16 and 17 illustrate for two actual cases studied by the Forest Service the pronounced effect that a regard for the profit or loss involved in handling different sizes of trees may have upon the financial success of a lumber operation. In these studies, individual logs representing trees of different sizes were followed from the tree through the mill, and the total cost of logging and milling, including the overhead charges, was determined from these cost records. The value of each tree in terms of current lumber prices was similarly determined from records of the amount and grades of lumber sawn from its component logs. As brought out in these tables, the difference between the selling price of lumber and the total cost of manufacture must cover both the operator's margin, which he will need to ensure a profit on the operation and to provide against possible losses, and the stumpage value of the timber, or the amount he can afford to pay for it if the operation is to yield the desired profit margin. For illustration, a profit of 20 per cent on the total cost of operation has been arbitrarily used in the tables; any other desired percentage of profit may of course be substituted. The stumpage values shown (see last column of Tables 16 and 17) represent the amounts an operator could afford to pay for trees of corresponding sizes in order to clear a profit of 20 per cent on his investment. The stumpage value might be further subdivided to recognize a profit on the stumpage itself, which the owner might reasonably expect; but since this is rarely considered in stumpage transfers it has not been differentiated. The profit and stumpage per tree were derived from the figures per thousand board feet by means of volume tables showing the volume in lumber by the

Scribner Decimal C log rule, of trees of different diameters. For Table 16 the volume table used was for net volume, after deducting from the log volumes for defect, sweep, etc. For Table 17, a gross log scale volume table was used.

TABLE 16.—*Stumpage values of red oak trees of different sizes; derived from lumber value and total cost of production* [1] *and assuming an operator's margin of 20 per cent of production cost for profit and risk*

Diameter breast high (inches)	Cost of producing lumber [2] (per M ft. b. m.)	Selling price of lumber (per M ft. b. m.)	Available for stumpage value and operator's profit	20 per cent profit on cost of production	Available for stumpage after deducting 20 per cent profit	
					Per M board feet	Per tree
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
13	33.43	37.89	4.46	6.69	−2.23	−0.11
14	32.18	38.10	5.92	6.44	−.52	−.04
15	30.98	38.80	7.82	6.20	+1.62	+.15
16	29.84	39.16	9.32	5.97	3.35	.39
17	28.70	39.53	10.83	5.74	5.09	.71
18	27.79	40.04	12.25	5.56	6.69	1.14
19	26.75	40.24	13.49	5.35	8.14	1.63
20	25.98	40.64	14.66	5.20	9.46	2.18
22	24.36	41.03	16.67	4.87	11.80	3.54
24	23.15	41.71	18.56	4.63	13.93	5.29
26	22.24	42.32	20.08	4.45	15.63	7.35
28	21.49	43.06	21.57	4.30	17.27	9.84
30	20.96	44.15	23.19	4.19	19.00	13.20
32	20.62	45.25	24.63	4.12	20.51	17.33
34	20.31	46.26	25.95	4.06	21.89	22.33
36	20.16	47.36	27.20	4.03	23.17	28.04
38	20.06	48.50	28.44	4.01	24.43	34.45

[1] Compiled from the following: GARVER, R. D., and MILLER, R. SMALL SAWMILL UTILIZATION OF APPALACHIAN HARDWOODS. U. S. Dept. Agr., Forest Service, Forest Prod. Lab. 103 p. 1929. All values are computed for net log scale (gross log scale, Scribner Decimal C rule, minus allowance for defect).

[2] Includes cost of sawing, skidding, milling, supervision, maintenance, depreciation, insurance, taxes, hauling and piling lumber, inspection, selling, roads, and trails. It also includes an amount varying from $0.26 to $0.44 per tree for additional brush lopping done after the log cutting was completed.

TABLE 17.—*Stumpage values of yellow poplar trees of different sizes; derived from lumber value and total cost of production* [1] *and assuming an operator's margin of 20 per cent of production cost for profit and risk*

Diameter breast high (inches)	Cost of producing lumber [2] (per M ft. b. m.)	Selling price of lumber (per M ft. b. m.)	Available for stumpage value and operator's profit	20 per cent profit on cost of production	Available for stumpage after deducting 20 per cent profit	
					Per M board feet	Per tree
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
13	31.85	29.85	−2.00	6.37	−8.37	−0.95
14	30.45	30.90	+.45	6.09	−5.64	−.85
15	29.20	32.00	2.80	5.84	−3.04	−.56
16	28.20	33.20	5.00	5.64	−.64	−.14
17	27.50	34.50	7.00	5.50	+1.50	+.40
18	26.80	35.95	9.15	5.36	3.79	1.19
19	26.20	37.35	11.15	5.24	5.91	2.18
20	25.65	38.80	13.15	5.13	8.02	3.37
22	24.70	41.65	16.95	4.94	12.01	6.70
24	23.90	44.50	20.60	4.78	15.82	11.27
25	23.65	45.80	22.15	4.73	17.42	13.75
30	23.10	50.10	27.00	4.62	22.38	27.86

[1] Compiled from Ashe (*5, p. 31*).

[2] The average costs per thousand board feet of the variables were: Felling, $2; skidding, $6; loading and railroad haul, $2; milling, $3.75; total, $13.75. The costs that did not vary, or varied only slightly were: Railroad construction, $2; inspection and loading, $2; selling, $2; office, $3; depreciation, $2.50; total, $11.50. The average total cost for yellow poplar was $25.25 per 1,000 board feet; 7 logs per 1,000 board feet.

The figures for red oak, presented in Table 16, are based mostly upon a single small circular-saw operation in western North Carolina, with additional information from three other small mills. The average output of these mills was about 7,300 board feet a day. The timber in which they operated represented a fair average for the culled mountain forest of the region.

It is evident that when operating costs and lumber values are as shown in Table 16, the smallest red oak tree an operator can cut and still make 20 per cent profit on his investment will be 15 inches in diameter. For any tree smaller than this he will have to be satisfied with a smaller profit or an actual loss. On the other hand, the amount available for stumpage value at a constant profit margin increases steadily with the size of the tree. Thus under the conditions shown in Table 16 a 15-inch red oak is worth $0.15 as it stands, while one only 3 inches larger is worth $1.14, and a 20-inch tree $2.18. From this point on the value increases quite rapidly with the diameter. When individual trees are worth as little as a dollar, the owner should not permit them to be cut without taking into consideration the added value they would have if left to grow a few years.

Figures like those in Table 16 are of course directly applicable only to the specific operation in which they were obtained, but the same general relationship of size to feasibility of removal exists in all cases (*6*). In a similar study, made at a hardwood band mill in the mountains of North Carolina (*5*), production costs and graded lumber values of yellow poplar trees were found to be as shown in the first three columns of Table 17. The amounts shown in the table for stumpage of different-sized trees, if a profit margin of 20 per cent is desired, were derived from the difference between values and costs, as in Table 16.

In the case cited in Table 17 the lumber from 20-inch yellow poplar trees was worth $8.95 per thousand board feet more than that from 13-inch trees, and it cost $6.20 less to log and manufacture it. A balance of $13.15 per thousand was available for stumpage and profit in the case of the 20-inch trees, but for the 13-inch trees a deficit of $2 is indicated. Figuring the profit margin at 20 per cent of the cost of production, trees below 17 inches d. b. h. had no stumpage value in this particular operation, while 20-inch trees had a stumpage value of $3.37. The stumpage value rapidly increases with increase in diameter.

Since both logging and manufacturing costs and the price of lumber are variables, Tables 16 and 17 can serve merely as illustrations. There will always be a neutral size, however, at which, if a fixed margin of profit is figured, the stumpage value is zero. In the cases cited this is between 14 and 15 inches (Table 16) and between 16 and 17 inches (Table 17). For any designated margin of profit this neutral size varies not only in different operations but also in the different parts of the same operation. An increase in logging cost—as, for example, if skidding costs increase $2 per thousand board feet in order to reach less accessible timber—will automatically cause an increase in the neutral size. Furthermore, large mills with considerable fixed and relatively small operating costs can afford to log to somewhat smaller diameters than small mills in which the operating costs are large as compared with the fixed expenses. The neutral size

will also vary with the species, owing to differences in lumber prices and costs of logging. In general, however, it is clear that some trees large enough to make saw logs are too small to be handled for lumber except at a loss. It is manifestly to the interest of sawmill operators to determine the neutral size for the different species and for different localities in the operation.

MEASURES NECESSARY TO KEEP FOREST LANDS PRODUCTIVE

The measures for fire prevention and logging practice that are outlined in the following pages represent the minimum of protection and care needed to put timberlands into condition for continuous production. On areas that have been depleted by fire and unrestricted cutting these measures should, of course, result in an actual increase in yield of timber; but they are not adequate to obtain the largest and most valuable perpetual yields. Recommendations for further treatment to produce full timber crops are added under a later heading.

FIRE PREVENTION

Fire prevention is the first means to be employed in restoring growth capacity and improving the forest for continuous production. It has been shown that fires have in the past caused more injury to the forest than logging or any other influence. Decay introduced where fire has scarred the trees without killing them discounts the future value of otherwise rapid-growing trees. Destruction of leaf litter and humus, especially on the dry sites, has set back for years the date when mature timber crops might be expected. The value of future stands is further endangered by the preponderance of sprouts over seedlings on burned areas. In these ways repeated burnings have gradually worn down millions of acres of thrifty forest land to a point where possible timber production is far below that on acres adequately protected. Fire prevention is therefore the first step upon which all future development of the forest depends.

CAUSES OF FIRES

Of the average of 2,322 fires that burned each year from 1923 to 1927 in the protected counties of Virginia, North Carolina, West Virginia, and Tennessee, probably 99 per cent were man-caused. Lightning fires are very uncommon in the southern Appalachian region. The causes of these fires are shown in Table 18.

TABLE 18.—*Distribution by causes of fires in the mountain, plateau, and valley regions of four southern Appalachian States,*[1] *1923–1927*

Causes of fires	Fires per year		Causes of fires	Fires per year	
	Number	*Per cent*		*Number*	*Per cent*
Incendiary	453	19.5	Lightning	14	0.6
Hunters, campers, smokers	376	16.2	Miscellaneous and unknown	650	28.0
Brush burning	320	13.8			
Railroads	267	11.5	Total	2,322	100.0
Lumbering	242	10.4			

[1] Virginia, North Carolina, West Virginia, and Tennessee. Acknowledgment is made to the State foresters of these States for the data from which the table was compiled.

The largest number of fires of known cause were classified as incendiary. This, however, does not necessarily mean that they were set with malicious intent. It is the usual practice in the Southern States (*10*) to report all uncontrolled or wild fires as incendiary, if set on purpose, whether or not the element of malice is present. Thus, many fires are probably reported as incendiary that are set to kill snakes, to uncover chestnuts, or in an effort to improve the range for grazing. In many parts of the region the sentiment against burning is growing, and the number of incendiary fires, though still large, is probably much smaller than it was 10 years ago.

The growth in the number of tourists, campers, and hunters who visit the forest each year carries with it an increasing menace of fire. More than 16 per cent of the total number of fires during the 5-year period were caused by such persons. Some of these fires are likely to be set in out-of-the-way places so that their prevention and control are both important and difficult. This class of fires should be influential in setting the standards for the organization of patrol and fire-fighting forces.

Railroads and lumbering may be classed together as occupational causes of fire. Together they are responsible for more fires than any other class—about 22 per cent of the fires classified in Table 18. Both are controllable, by mechanical and other means, and involve risks that can be foreseen and prepared for more readily than those from the other causes.

Being man-caused, the majority of the southern Appalachian fires are avoidable, and the outlook for prevention is therefore more encouraging than, for example, in the Rocky Mountains, where 50 per cent of the fires in the decade 1916–1925 were caused by lightning. Another circumstance that bears upon the danger of fires starting, as well as upon the possibility of prompt and effective suppression, is the degree to which the forest lands are settled. While there are no completely satisfactory statistics from which this can be accurately determined, the 1920 census of rural population of individual States (which includes the inhabitants of cities of less than 2,500 population), compared with the forested area, furnishes at least an indication. According to these figures, Maryland, Virginia, West Virginia, North Carolina, Kentucky, and Tennessee have a forested area of only 7 acres for each rural inhabitant, while in six Western States—Washington, Oregon, California, Idaho, Montana, and Colorado—the area for each rural inhabitant is 33 acres. Since more people are living in or passing through the forest in the southern Appalachian region than in the Western States, the risks of man-caused fires are greater, but on the other hand control measures are more easily and quickly applicable.

NEED FOR COOPERATION

Since the loss from forest fires affects both the individual timberland owner and the public, protection from fire is logically a matter for public and private cooperation. The present accepted Federal and State policy contemplates a protective fund contributed half by timberland owners and half in equal shares by the Federal Government and the States (including the counties). This fund is

administered by the States. The fire-control forces that can be mustered under this fund, however, are generally too small to furnish the protection needed at all places in a territory as rugged as the mountainous parts of the southern Appalachian region. Thus, while the efficiency to be gained through the state-wide protective organizations makes it desirable that all timberland owners should contribute to it, the private owners should cooperate even further by reducing their own fire risks and hazards and providing for emergency suppression forces. The private protection of forests, in relation to that afforded by public agencies, is comparable to private protection of homes and factories in cities with efficient fire organizations.

By cooperating with one another and with State forces, owners of timberlands can obtain good protection at a relatively small cost, which can be considered as insurance upon the improvements, equipment, and other investments in growing timber. Protective organizations of timberland owners have functioned successfully in many parts of the United States. In West Virginia two have been in existence for a number of years; groups of landowners have been organized more recently in other States. The success of individual and of local organizations, however, will be increased in proportion to the progress of the public effort to prevent fires. This emphasizes the need of widespread cooperation.

Past experience has resulted in the development of efficient methods of fire protection. The needs of the future are, first, to supply the funds necessary to extend and intensify these methods and, second, to bring about a universal appreciation of the value of forests and of the many-sided loss from forest fires. Intensive campaigns of education among the users of the forest, and insistence upon the rigorous enforcement of laws aimed to prevent fires, are two ways in which timberland owners, by taking part in the general effort against fires, can help to safeguard their own properties. A third and, in the long run, the least expensive and most efficient method is the more and more intensive development of forest lands as actively producing resources. When this is accomplished fire prevention will become merely incidental to forest management, as it is in some of the European countries.

GENERAL MEASURES

The details of fire-control procedure will depend upon the kinds of risk and their relative importance, the kind, amount, and distribution of inflammable material, the number and reliability of the local inhabitants who can be called upon to detect and suppress fires, the age of the timber, the topography, and other considerations. There are certain general principles, however, that are applicable to all conditions.

ORGANIZATION

The outstanding requirement for successful protection is a responsible, effective, and easily working organization of funds and personnel, maintained by the State in cooperation with the counties, the Federal Government, and individual or organized timberland owners. The functions of the organization must be to prevent,

detect, and suppress fires, and since burning is largely due to general ignorance of the damage done by fires an important part of the work will be educational.

Educational activities are now recognized by all the States as of fundamental importance in the campaign against fires. Efforts are being made to reach all communities and all forest users, through the schools, churches, and such organizations as the Boy Scouts. Special lecturers are employed on this work in some States, and moving pictures and other means of arousing local interest in preventing fire are widely used. The added danger from fire represented in the increased use of the forest by fishermen, hunters, campers, and tourists calls for constant reiteration of the importance of preventing and extinguishing fires. The diffusion of information upon the damage from fire has thus become one of the essential duties of fire-protective organizations.

All the States included wholly or in part in the Appalachian region have organized fire-control forces. Because of inadequate financial support, however, these organizations have never been able to command the man power and equipment to render them fully effective. The limited funds available have been stretched out over large areas, providing in many cases only a skeleton system of fire protection and leaving many other areas without even the beginnings of an organization. Fire-prevention activities have been largely discretionary with the individual counties, the degree of activity in any county being determined not only by the adequacy of the State's resources but also by the willingness of the county to cooperate through voted funds. Two States, Virginia and West Virginia, have laws which provide that the counties shall pay fire-suppression costs. Many of the counties in the southern Appalachian States have elected to remain without protection. It is to the interest of timberland owners to see that protection is furnished and to amplify it by their own action to the extent necessary to safeguard their properties.

The central State organization has, or should have, a detailed plan of protection for the several counties. The average extent of woodland in a county is about 150,000 acres. A county of average size is as large an area as can usually be handled with any degree of effectiveness by a single head warden. The head warden should be employed during the fire season and should work under the direction of the central headquarters. The head warden's district should be subdivided into small areas, each in charge of a warden. While the size of these districts will depend upon local conditions—particularly the distribution of the woodlands, the seriousness and distribution of the risks, available means of transportation, and the readiness of the local residents to cooperate—they ought not to include more than 10,000 or 15,000 acres of woodland.

If a lookout system is provided, the number of wardens may be less than if the detection of fires is dependent wholly upon patrol. The lookout system, in which observers are stationed during the fire season at fire towers or other points of vantage, has proved very successful in most of the southern Appalachian States and elsewhere and is coming more and more into use. In clear weather lookouts

can see effectively to a distance of at least 10 or 15 miles, representing an area of 200,000 to more than 400,000 acres. Smoky or hazy weather, of course, greatly reduces the visibility. In general, the effectiveness of the lookout system depends upon the reliability, intelligence, and alertness of the men selected for this duty, and equally upon the reliability of the supporting system of telephone communication and the perfection of the fire-fighting organization ready to start for a fire at a moment's notice and remain with it until it is extinguished. It is essential that the local telephone lines within the area commanded from the observation point be so organized as to permit the lookout to notify all wardens immediately of the location of a fire and particularly those located nearest the fire. Fire towers are more necessary in flat or rolling country than in mountainous country where observers can be stationed on commanding mountain tops or ridge crests.

North Carolina plans a system of 40 lookout towers for about 4,200,000 acres of forest land in 25 mountain counties. This would give an average of about 100,000 acres for each tower, corresponding to a radius of a little over 7 miles. The system is somewhat more intensive than the general one above suggested, but will be more effective during periods of low visibility. Eight towers and two mountain tops were manned in the fall of 1927 in cooperation with counties and individuals and in the case of the stone tower on Mount Mitchell in cooperation with the Federal Government.

Local wardens are customarily paid for actual time spent in fire patrol, fire fighting, burning protection strips, posting warnings, and other prevention activities. Their duties include the establishment of patrol routes, the custody and effective distribution of fire-fighting tools, and the organizing of a reliable fire-reporting and fire-fighting system manned by local residents. Much depends upon the character and local reputation of the men appointed as wardens. The selection of men who can command the respect and ready cooperation of their neighbors will result in reducing the cost and increasing the effectiveness of the system.

Protection can not safely be limited to the most valuable, most promising, or best located stands; there is always a risk of fires spreading into them from less valuable lands adjoining. The preventive system should cover all forest lands, regardless of location or quality.

The cost of the system will vary according to the extent and severity of the risk, the cooperation of the local residents, roughness of the country, and the promptness with which a fire-fighting crew can be transported to the fire. In rough country and areas difficult of access ample roads and trails for reaching fires quickly must be developed and kept clear. Heavy accumulations of slash must be guarded with special care. Thus the cost of preventive measures may rise in extreme cases to as much as 10 cents per acre per year. In the southern Appalachian States, however, the present standard on protected areas is attained at costs ranging from less than 1 cent to a little more than 3 cents an acre a year. The amount set up by the cooperative agencies as the estimated need for average mountain timberland in the entire region is 3½ cents an acre a year.

FIRE-WEATHER WARNING SERVICE

Past studies indicate that the efficiency of the protective organization can be greatly increased through the agency of a fire-weather warning service. As the result of a study of storm movement and forest inflammability, McCarthy (*42*) showed that the danger of fire in the forest changes with weather conditions, which vary with the progress of storms across or near the Appalachian region. Since the storms travel generally from west to east, the time at which their rate of movement will bring them to the southern Appalachian region can be forecast. McCarthy concluded that conditions of wind, sunshine, and relative humidity favorable to forest fire are the regular aftermath of a storm, and can be forecast with more certainty than precipitation; and that unusual hazard is caused by continuation of high pressure (marked by shifting of the winds from the ocean and gulf to a continental source, bringing colder and drier air and fair weather) over or west of the Appalachian region, or by the passing of a storm without precipitation in the region. The advantage of a fire-weather warning service is that it would permit the shifting of the fire-fighting personnel and the concentration of the largest man power in preparation for times of special danger from fire. Such systems are now in effect in some other forest regions of the United States, but none has yet been put into operation for the southern Appalachian region.

REDUCTION OF RISKS

Since the leaf litter on the floor of the forest is the principal means by which fires spread in the southern Appalachian forests, the burning or scattering of brush left in logging is neither necessary nor effective except in limited areas of special risk. These measures are costly, and more can be gained at less expense by well-organized protective personnel. In specially hazardous places, however, as along railroad rights of way, the ground should be kept clear of inflammable material. Along railroads a strip at least 4 rods (66 feet) wide on each side of the track should be cleared of brush and leaves at least once a year, by burning. The responsibility for keeping the right of way cleared should fall to the railroads, but since the width of the right of way is ordinarily inadequate, the cooperation of the owner of adjoining land is necessary. In Virginia the railroads are permitted, with the consent of the owner, to burn waste and woodland in strips 50 feet wide adjacent to those burned on their own lands, and may be authorized to burn in spite of the owner's protest. The burning of strips of adequate width should be assured by proper legal measures, or the railroads should be required to furnish equivalent protection by speeder patrol after trains in addition to the burning of the right of way at points of hazard.

The use of spark arresters and the systematic inspection of these and of ash pans should be required. This should be in addition to, and not in lieu of, the controlled burning of the protective strips, since practical difficulties experienced in the control of protective devices on locomotives show that these are not entirely reliable. Railroad section men should be instructed to extinguish fires which originate on or near rights of way.

Operators of portable sawmills should be held responsible for damage from fires starting from their sawmills. In addition they should be compelled to screen their stacks and to organize their mill crews to extinguish fires which may start near the mills. Slash and inflammable débris should not be allowed to accumulate near a mill, and isolation strips at least 8 rods wide around the sawdust pile as well as around the sawmill should be cleared of débris by burning or other means when the mill is so located as to constitute a risk.

The burning of slash, brush, or grass, whether to eliminate risk or to clear lands for agriculture, is in itself a risky undertaking and a common cause of fire in the southern Appalachian States. The record of fires in Virginia and North Carolina during the three years from 1926 to 1928, inclusive, shows that brush burning caused 23 and 22 per cent, respectively, of the fires reported in these States. Such burning should be very carefully controlled. It should be done only by responsible persons and in cloudy or damp weather, free from wind. The several States have more or less satisfactory laws covering this subject, but few if any are wholly adequate. Persons who propose to burn brush should be expected to notify in advance the occupants of adjoining lands, as well as the local firewarden, but such notice should not excuse them from liability for damage should fires escape from their lands. Persons setting any such fires should be held responsible for extinguishing them.

In general it is important that responsibility for the escape of fires should be recognized. The enactment of laws recognizing the value of standing timber, including reproduction and young growth, and fixing the right to civil damage from burning, will do a great deal to check carelessness in allowing fires to spread. Effective means should be found to insure the clearing up of rights of way along much-used highways or adjacent to woodlands, and it should be a part of the duties of the protective organization to placard such roads and patrol the more hazardous places during the fire season. The menace from camp fires and hunters should be cared for by legislation, and the laws should be energetically enforced. As a means of protecting the forest against undue risk the governors of the States should have the power to close the hunting season during a very dry period, when a large number of hunters are a serious menace to the forest.

SPECIAL MEASURES

Fires in logging slash are hotter, more destructive, and more difficult to extinguish than the ordinary leaf-litter fires, and slash-covered areas therefore require special protection. In the moist slope and cove forest the slash as a rule decays to a not very inflammable condition in four or five years after logging, but on the drier slopes and ridges it may remain a serious menace for a year or two longer. The danger from slash on the ridges and slopes is greater also because the slash there dries out quickly and may become inflammable within a few hours after rain. Fires that start on dry slopes may gather enough headway to carry them over large areas of moist-site forest as well.

MOUNTAIN FORESTS

The extreme fire risk is that in the spruce forest after logging (fig. 8), where the slash is usually so heavy that no methed of disposal to reduce the fire hazard is practical. Although the natural spruce forest is damp enough to resist the encroachment of fire and to cause the decay of small litter to a practically safe condition in three to five years, when logging has opened up the stand the slash dries very rapidly and becomes extremely inflammable. This drying out of the slash also delays decay and extends the fire menace until the crowns of the second growth have established a shade. Where there is clear cutting, devastating fires can be prevented only by the most unremitting care. Under the system of partial cutting that will be discussed later, the risk from slash in the spruce forest will be greatly reduced. A large portion of the logged spruce land in the

FIGURE 8.—The slash after clear cutting in spruce forest remains for years an extreme fire menace. (Pigeon River watershed, Haywood County, N. C.)

Black and Balsam Mountains was burned as a result of logging operations. The discharge of sparks by locomotives pulling heavy loads on steep grades has been responsible for numerous fires. Even though fires are avoided at the time of logging, the inflammability continues and is increased by annual accumulations of dead grass, weeds, and leaves. After the logging is over, the danger of fire comes mainly from campers, hunters, and visitors to the mountains.

The special fire danger caused by logging in the mountain forests should be guarded against in the following ways:

All slash created in clearing for the railroad should be burned, together with all light slash on a protective strip along each side of the railroad. The width of the strip will depend upon the topography, the presence of water, and other physical features. In level country and on the low side of the track on slopes, 4 rods may be sufficiently wide for safety; but on grades where locomotives use

forced draft it may be necessary to widen the strips to as much as 6 rods. Around steam skidders or other stationary engines the ground should be cleared of inflammable material for a radius of at least 8 rods. Dry and windy days should not be selected for the burning. The first burning ought not to cost more than $10 an acre, or $80 a mile of strip 4 rods wide, even when the slash is fairly heavy, except perhaps in the spruce forest. It should be possible to keep these strips clear by later burnings at a cost of not more than $30 a mile.

All engines should be equipped with approved spark screens and other protective devices necessary to prevent the scattering of fire. Extreme care should be taken to keep the spark screens in good condition. They should be inspected frequently and the engineers held responsible for their condition. Similar responsibility should be imposed for the dumping of ashes in safe places, such as cuts.

Effective patrol should be maintained by the operator, with special patrol after all trains during danger periods. The patrolman should be furnished with the necessary fire-fighting tools, which he should keep at convenient points; and he should have such means of communication as might be required to make his work effective.

When a fire is discovered, the operator should at once send to the spot a crew of men large enough to control it.

In the spruce forest it is well to leave strips of green timber as fire barriers on both sides of logging railways and between different parts of the operation. These should be 50 or 75 feet wide, or as much as 100 feet on slopes above the track. They may include the timber available from one or more skidder sets so as to facilitate its removal at the end of the operation.

After the close of the logging operation and the removal of all steam equipment, the cut-over area should be under patrol during fire seasons for four or five years after cutting in the hardwood forest, and for 10 years after cutting in the spruce forest. In the hardwoods, the patrol may be at the rate of one man for a watershed of 5,000 or 10,000 acres containing slash. In the spruce the district patrolled by one man should not exceed 3,000 or 4,000 acres. The patrolman should have access by telephone to a lookout or the local headquarters of the fire organization of the region. The annual cost of such patrol will vary from about 7 cents an acre for the spruce to about 2 cents an acre for the hardwood cut-over areas. When the danger from slash has abated, general fire-preventive measures should be sufficient. Where partial cutting has been employed the intensity of the patrol can be lessened except at points of special danger, as along railroads.

PLATEAU AND VALLEY FORESTS

Fires can be much more easily prevented in the isolated strips and blocks of farm woodland than in the large forest areas of the mountains. These woods are under more constant observation, communication is easier, and fire-fighting forces can be more quickly assembled and brought to the scene of the fire. There is little excuse for fire in farm woods. Nevertheless, considerable areas in the aggregate are burned over each year and great damage is done.

In the foothills of the mountains and on the long parallel ridges in the Appalachian Valley the plateau forest sometimes covers extensive areas and here the suggestions for fire prevention that were given for the mountain forest apply. Areas cut over less than five years should be protected with special care. Often the observer system may to advantage be substituted for actual patrol. Owners of farm woods and timber tracts on the plateaus should insist upon full cooperation of their counties in the State protective system. They should themselves use the utmost care to prevent the spread of fires set in lands adjacent to their woodlands and should observe constant vigilence each spring and fall to detect promptly any fire that may start near by.

LOGGING PRACTICE

IMPROVEMENT OF POOR STAND CONDITIONS

The additional treatment required to maintain forest production in some measure, once adequate fire protection is assured, is very simple. What form it is to take must be determined from the conditions now encountered on cut-over areas—conditions which in detail are variable in the extreme. However, the situation may be sufficiently well characterized by the following four general conditions that, according to the data already presented, are most widely prevalent:

(1) Deficiency of good trees and of desirable species like yellow poplar, red oak, and white pine, among both the large and the smaller size classes.

(2) Surplus, in both size classes, of defective trees and of less desirable species like sourwood, red maple, and black gum.

(3) Deficiency of tree reproduction of desirable kinds.

(4) In burned stands, a heavy preponderance of sprouts in the reproduction.

Whether or not these conditions can be corrected in the course of logging without extra expense depends entirely upon the density, quality, and accessibility of the stand. The treatment indicated in the majority of cases will be as follows:

Emphasis should be placed upon getting rid of as many defective trees as possible along with the more salable timber, so as to clear the way for the growth of reproduction.

Where promising small trees occur in groups it is usually desirable to leave them for continued growth.

Small isolated trees, on the other hand, are likely to develop limby trunks and spreading crowns, and may best be removed if practicable. The cleared spaces thus left between groups of maturing second growth will later be filled with tree reproduction.

Care should be observed in logging to prevent breakage of the trees to be left for growth. Broken trees should be removed.

To ensure the continuance of good species in the future stand the seed supply should be built up, where inadequate, by reserving a few well-distributed seed trees.

After logging, the stand should not be cut over again until it is in such condition that the second cutting will leave half or more of the area stocked with sound young trees. This new stand, reinforced by reproduction in the openings left by cutting the larger trees, will

comprise the growing stock for future cuttings under a plan of management such as will be discussed later. The time interval between the first and second cuttings should be determined by the size and condition of the stand left and the growth capacity of the site, and not entirely by commercial feasibility of operating. Only on the best sites with a fairly good young stand left after the first cutting should a second operation be considered in as short a time as 10 years. On dry sites, or when only a thin stand of young trees is left after the first cutting, a return cutting may not be advisable for 20 years or even longer.

These principles can be adapted to a wide range of forest conditions. They permit the removal of large sound timber along with defective trees, large and small, and their object is to provide space for the growth of promising young trees and the reproduction of desirable species. As compared with the old destructive methods of culling, some sacrifice may result where products from the inferior trees cut can not be sold to advantage. How far an operator will wish to proceed with this practice will depend upon what he desires to invest in measures that may not offer an immediate financial return. The line between constructive and destructive cutting is a critical one, and great care must be observed if the forest is not to be left in a poorer rather than a better condition. In particular, every effort should be used to free the ground of the shade and root competition of the defective and otherwise unpromising trees. The aim should be to open up the forest, leaving as much as possible of the promising stand in groups.

Where many of the trees are defective or unpromising so that only a scattered stand of small trees would be left under the selective treatment above outlined, the cutting should be as clean as possible except for a few trees of desirable species left for seed production. On areas that are not too inaccessible, markets can usually be found for railroad ties, mine timbers, cooperage stock, pulpwood, fuel wood, or other small products that will afford a means for disposing of trees unfit for saw logs. There are, of course, areas that can not be profitably logged at present under the suggested treatment. They include the heavily cut over (pl. 11, A) and severely burned land, as well as steep, rugged, or remote areas that are not well enough timbered to justify the relatively high cost of logging them. Unless an actual investment were to be made on such lands in anticipation of deferred returns, no productive treatment for them would be possible other than protection from fire for the period necessary to develop a paying stand.

Nearly every large tract of timberland contains more or less dry-ridge and upper-slope land where timber is short bodied and the yields are low. These lands have usually suffered severely from fire. They have been culled, largely for chestnut oak, and the proportion of less desirable species and of defective trees has thereby been increased. Also, they are the more difficult of access, so that light cuttings would be too expensive to be justified. The best treatment here is to log as heavily as practicable, removing especially the poorer species and defective trees, but to leave a few trees of good species to furnish seed. A period of several decades will intervene before any further cutting will be practicable or desirable.

The case is different on north-facing and east-facing slopes, on lower south and west slopes, and in coves and on flats where relatively moist conditions prevail. (Pl. 11, B.) Here growth is more rapid, there are more tree species, and a larger number of them are of special value. Cuttings can be made more frequently and for a greater variety of products than on the drier sites. An example of selective logging done cooperatively by the Appalachian Forest Experiment Station and Berea College, on the latter's forest tract at Berea, Ky., will serve to illustrate the values and costs of such logging in culled stands on good sites.

The selective logging at Berea was done in 1923. About 33 years earlier the stand had been culled of everything merchantable at that time, but many small trees and some large defective ones had been left standing. At the time of the selective cutting many of the smaller trees previously left had become merchantable. This later cutting took 420 trees from an area of 2.8 acres laid out by the experiment station as a sample plot. The volume removed amounted to 10,000 board feet. This was logged and sawed up at a total cost of $142.74 into lumber valued at $242.50. The combined stumpage value and profit, not counting wood cut for fuel for Berea College, therefore amounted to approximately $100, or $35.63 per acre. Only average cost figures were kept, so that it is impossible to determine the stumpage and profit for the different kinds and qualities of logs. The figures indicate, however, that the low grades of lumber produced were logged at a loss, while for the higher grades the stumpage and profit amounted to more than $25 per 1,000 board feet. The cutting removed the overmature and defective as well as some of the sound timber. It left the area of 2.8 acres with an open stand of only 173 trees, but these were of good species, sound, well-formed, and in fine condition for growth. In five years the average diameter of the trees left had increased 3 or 4 inches, and many smaller trees had grown up into the openings. The area could probably be cut over again with profit at the present time, but by postponing this second cut for a few years a much higher yield will result, and a better stand can be left for future growth.

On steep slopes some erosion may occur after a heavy opening up of the hardwood forest, but unless the area is repeatedly burned there is little danger that it will become serious. The network of roots will act as a preventive, and this will be quickly reinforced by the growth of tree reproduction and forest shrubs. The chief danger is in deeply worn skid roads, which are likely to become run-off channels. They should be filled at places with logging slash and stones.

In the spruce forest there now remain only a few small bodies of timber that are available for cutting. The general practice in the past has been clean-cutting for saw logs and pulpwood, resulting in heavy accumulations of slash and destructive fires. (Fig. 9.) A few examples of selective cutting in West Virginia indicate that this method can be used successfully. The danger of wind throw is serious if large trees are left exposed by the cutting; not so serious if large trees are removed. The removal of only the largest trees will reduce the density of slash and permit its early decay under the shade of the trees left. It will also favor the reproduction of spruce

and fir, which are much more likely to become established in the partially cut forest than in the dense hardwood reproduction that comes in on clean-cut areas.

SELECTION OF SEED TREES

The purpose in leaving seed trees is to provide a means for preserving desirable species in the future reproduction. The adverse effect of repeated cullings on the reproduction has already been noted. The continuation of this process would eventually deplete the forest of its best species, especially if the reproduction were destroyed by fire. Seed trees do not have to be particularly large trees, and if numerous trees are left for growth that are near the profitable size limit for lumber (as defined in a preceding section)

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FIGURE 9.—Steam logging in the spruce forest of the Black Mountains, N. C. All merchantable trees were cut, leaving a heavy inflammable slash. Fires in the slash later destroyed all the spruce and fir that remained after cutting, leaving the area as shown in Figure 6

no other provision for seeding need be made. Where stands are cut heavily, however, seed trees should be specially reserved.

The number and distribution of trees for adequate seeding will depend upon topography, weight of seed, and reproductive capacity of the species dealt with. Heavy seed, like that of oak, hickory, walnut, cucumber magnolia, and gum, falls close to the trees, and will roll, be washed, or be carried by animals for short distances only. Five or six well-distributed heavy-seeded trees to the acre will go a long way toward seeding in satisfactorily on flat lands, if the seed is not subject to especially heavy losses; on hilly land even fewer trees will serve. Light, winged seed, like that of yellow poplar, birch, ash, basswood, maple, and the conifers, is widely distributed by wind, and an area of 1 or 2 acres may be fairly well seeded in by a single well-located tree. A commanding position and favorable prevailing winds are influential in extending the scope of seed distribution.

Seed trees should of course be of seed-bearing age or size. This size or age varies with the species, the site, and the condition of the stand in which the trees have been growing. Seed trees should have full and healthy crowns and should have received full light from overhead and preferably some from the sides as well. They should not be smaller than 10 inches in diameter. Dominant trees of this size are usually already becoming good seed producers. Production increases as the tree grows, up to an advanced age, when the size and fertility of the seed yield diminish. Seed trees may be thrifty, dominant, well-crowned second-growth trees, capable of making growth on their own behalf as reserves for the next cutting; or they may be mature trees that are still active bearers. Small, thrifty, well-crowned trees are superior to large ones, since they possess low intrinsic and high potential value, are capable of making a good growth, and may be harvested as especially valuable timber trees at a later cutting.

The cost of seed trees amounts to the stumpage value, which is indicated for different sizes in Tables 16 and 17. In most cases leaving relatively small, sound trees will be an investment in growth as well as in seed production.

MANAGEMENT OF FORESTS TO PRODUCE FULL TIMBER CROPS

To get out of forest land the highest possible value in timber trees requires more intensive and detailed treatment than fire protection and the few simple cutting rules designed merely to restore or maintain a moderate production. A detailed program of cutting and thinning or weeding should be adopted, and for large tracts this program should be elaborated into a definite schedule of cuttings, or management plan, such as is fully discussed in the standard works on forest management and elsewhere (*19*, *29*). In such improvement cuttings, present income will as a rule be partly subordinated to the prospect of larger and continuous returns. In the following discussion of management of forests to produce full timber crops, farm woods, which present certain economic possibilities for management that set them apart from larger tracts, will be handled separately. In general, methods of treatment will be much the same as for individual stands of timber in the larger tracts.

Once the forest condition necessary to produce full timber crops is attained, it can be maintained indefinitely. This may be done by harvesting successive crops at yearly or other intervals, the size of the crop cut being held down to the amount of growth that the stand can make. This in turn is governed by the quality of the particular soils in which the stand grows. The advantage of thus limiting yield to growth, by what is termed sustained-yield management, is that such management substitutes a relatively large, fixed, and valuable yield for the smaller output that would be available sporadically if the timber was allowed to grow without systematic treatment. Sustained-yield management guarantees a steady supply of wood products conformable to the needs of local industries. In their present state, however, the southern Appalachian forests fall far short of the point of productiveness at which they will sustain a continuous yield of the products desired and must be built up to this point.

The essential feature that is now universally lacking is a reserve of healthy desirable timber with ages so balanced from seedling up to maturity as to sustain a continuous yield. Such a reserve of young trees is called an adequate or "normal" growing stock.

The best way to go about acquiring a normal growing stock is (1) to conserve promising immature trees and (2) to encourage a full reproduction of desirable species. A general idea of the conditions to be met and of the reproductive and other characteristics of the various species is given in the first part of this bulletin. These characteristics, particularly the soil and light requirements of the individual species, must be carefully regarded. Most of the desirable species, as well as many of the less desirable, require ample light for reproduction and growth. Yellow poplar, white ash, black cherry, and the pines are examples of desirable light-demanding species; hemlock, beech, and maple are more shade-enduring. Spruce and fir are desirable species that will reproduce and grow under moderate shade.

Stirring the litter on the forest floor so as to bring seeds in contact with mineral soil is important for yellow poplar and more or less advantageous for other species, although it is not necessary for spruce, fir, hemlock, birch, and a few others, which are able to reproduce satisfactorily on moist decomposed woods litter. For the species that require mineral soil, logging usually disturbs the litter sufficiently to accomplish the purpose.

The frequency with which a stand may be cut depends upon the quantity and size of the timber previously reserved and on its growth rate. When a good growing stock has been established, light cuttings may be repeated at intervals of 10 or 15 years. In the absence of a good growing stock time must be given to develop one, which may double the interval between cuts in any particular stand. The entire tract may, however, be divided into units for annual cutting in such a way that by the time the whole area is cut over the unit first operated will again be ready for cutting. In this way the tract will yield annually and continuously.

FULL-CROP MANAGEMENT FOR LARGE TIMBER TRACTS BELOW THE SPRUCE ZONE

METHODS OF CUTTING

The two general methods of cutting are clear cutting and partial or selective cutting. In clear cutting the entire stand is removed—small as well as large trees—except for such trees as may be left for seed. In selective cutting, trees that are large enough to yield a substantial profit are removed and the promising young trees are left for further growth, even though some of them may already contain merchantable material. The young trees selected to be left should have long, straight, sound boles and dense, fairly compact, and healthy crowns. Such small trees may represent 40 or 50 years of growth already attained, and may need only a relatively few years more to become large enough for some select use. The choice of treatment will depend to some extent upon whether or not all the trees present in a stand can be marketed profitably. For example, a pure stand of yellow poplar or of pine may be entirely merchant-

able, the larger trees for lumber and the smaller for pulpwood or some other product; while in a stand of mixed species and sizes, only a part of the trees may be large enough to justify cutting for any purpose. In a given forest tract clear cutting may be justified for some stands and partial cutting for others. The cutting method to be used should be decided upon in advance as a part of the general management plan for the tract and in accordance with the best prospective income and the reproductive and growth characteristics of the species present.

Examples of the utility of clear cutting are presented in the early charcoal operations mentioned at another place in this bulletin, resulting in fine stands of even-aged second-growth hardwoods. Here trees of all sizes and species could be used, although it is by no means certain that even then all were used with greatest profit. For the stands that have resulted, however, present standards of value rarely make clear cutting advisable. These stands should rather be considered in terms of the sizes at which each species can best be cut to command the highest price. Selective cutting is therefore recommended.

In mixed stands, selective cutting is thus a means of growing each species to its most profitable size. Since the species differ in growth rate this means assigning a different period of life, or "rotation period," to each species or to groups of species resembling each other in growth rate. For saw and veneer logs large trees with long, clear boles are necessary. As was indicated in Tables 16 and 17, value increases rapidly with size and 24-inch trees are considerably more valuable than 18-inch trees. The diameter selected as the minimum for cutting should be determined by balancing the greater value of large trees against the time required to reach large size, which will be longer for white oak than for poplar or basswood. On the other hand, some species, like black locust and scarlet oak, can not be grown practicably to large size; small-pole size is about the limit for the former, and tie size (14 or 15 inches d. b. h.) for the latter, because of the danger of loss from decay above these sizes. Dogwood reaches mature size at 8 to 12 inches d. b. h. (*17*).

Partial or selective cutting can be practiced by removing either single trees or small groups of trees. Group selective cutting recommends itself especially where clumps of good reproduction are already present on the ground, ready to spring up into the openings thus provided for them. The severity of the cut should depend upon the species, density, and commercial value of the stand. In stands of northern hardwoods (beech, birch, and maple) and hemlock, reproduction will take place after lighter cutting than is necessary for the moist slope and cove forest. Where the reproduction to be encouraged will be of yellow poplar, ash, basswood, red oak, white pine, or other valuable light-needing species, heavier cuttings are justified. In the dry-slope and ridge forest cuttings should be lighter and at longer intervals than in other forest types because of the slower growth and thinner stands.

Partial cutting is obviously best suited to logging by animals, rather than by machine. Skidding by overhead or ground cables would be ruinous to the trees left and to the advance reproduction.

The summaries of stand and reproduction presented in Tables 5 to 7 show that a start toward a growing stock of different-sized

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EXTREMES OF MANAGEMENT IN MOUNTAIN FOREST

A, A heavily cut-over south slope in southern Appalachian hardwoods. Some of the small trees are of promise but many are defective and should be removed to provide light and space for reproduction; B, a stand of mixed hardwoods in the lower moist-slope forest after a selective logging. The openings left by the logging, 12 years before the picture was taken, are rapidly being filled by young trees and by the spread of the larger tree crowns.

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REPRODUCTION OF SOUTHERN BALSAM FIR AND RED SPRUCE FILLING A SMALL OPENING IN THE SPRUCE FOREST ON MOUNT MITCHELL, N. C.

trees is already present on most of the cut-over areas. Some of the trees left as too small in past cuttings have since reached merchantable size and smaller trees are now filling the spaces between them. By a proper regulation of cuttings, marketable material can be removed at intervals, while the growing stock is being brought into order. Areas that have recently been heavily cut over or that have been severely burned can not, of course, be expected to yield a paying crop at an early date, but there are many tracts that are rapidly approaching a merchantable condition. The history of the past culling operations contains numerous instances of stands reworked four or five times at short intervals before being entirely exhausted. This is an indication of the possibilities in selective cutting. By allowing longer intervals between successive cuts and by reserving promising trees for later removal the owner may expect, instead of denudation, a perpetuated and steadily improved yield.

Excellent opportunities for forest management are afforded by well-stocked second-growth stands, the growth and yield of which were shown for different sites in Tables 8 and 9. If unburned, or at least not severely burned, such stands represent the best condition of growing stock for continuous treatment that the present southern Appalachian forest has to offer. As far as can now be foreseen, the ideal result of many years' management of a forest tract would be a series of such stands, graduated according to age, so that a continuous succession of cuttings would follow as the different stands matured.

It would not be necessary, however, to cut the stands clean. As previously shown, this would be suitable only when all or practically all the trees can be cut with profit. The young stands can be managed by thinnings (to be discussed later) and the older stands by partial cuttings in which select trees of fully merchantable size are removed, leaving the larger number of smaller trees to increase in volume and quality.

IMPROVEMENT CUTTING AND GIRDLING

The first steps in management for full-timber crops in the hardwood forest, with or without a mixture of pine and hemlock, will be generally the same as those previously recommended for keeping forest lands productive, but with some additional improvement measures. These additional measures, which represent an investment in the development of an adequate growing stock, include the removal of the large unmerchantable timber and the poor small trees to insure the best growth of the desirable young trees and reproduction. If the quantity of merchantable timber is not sufficient to justify immediate logging the stand may be left until a paying yield, made possible through the growth of smaller trees, can be obtained without overcutting. Trees on the border line of value for lumber (Tables 16 and 17) will soon reach profitable size.

Improvement cuttings of this nature can be made relatively cheaply. One that was made in 1929 on the Natural Bridge National Forest in Virginia [11] will serve to illustrate methods and costs. The stand was chiefly of oaks, chestnut, and white pine, with yellow

[11] The data given are from a report on the cutting by Forest Supervisor H. M. Sears.

poplar and hemlock in the coves, and with considerable hickory, black gum, red maple, and other species for which there was no sale value at the time. A heavy reproduction, chiefly of white pine and yellow poplar, had appeared, following the opening up of the stand by chestnut-pole cuttings in 1920–21 and 1924–25. In 1928 the saw timber on this area was selectively logged. No white pine, yellow poplar, white oak, or red oak trees were removed that were less than 16 inches d. b. h., but the other species were marked for cutting to smaller diameters. The saw timber removed in this cutting averaged about 5,000 board feet per acre.

At least 1,500 board feet per acre was left standing, contained in smaller trees from 12 to 18 inches d.b.h., largely white pines, poplars, and red oaks, but including also a great many small and a few large trees of less valuable kinds. This stand was still heavy enough to imperil the future growth of the excellent white pine and poplar reproduction, and an improvement cutting was accordingly made in which the less promising species were felled or girdled. As a rule, only the saplings 4 inches d.b.h. and less were actually cut, all trees larger than this being girdled. The average number per acre of trees cut or girdled was 293, and of these more than 90 per cent were in the 2 to 4 inch class. These small trees were mostly dogwood, sourwood, and red maple. Of the trees 9 inches and larger that were girdled, most were of red maple, black gum, and hickory, but there were only 10 such trees per average acre.

The expense of the actual felling and girdling was $1.35 per acre, under somewhat higher labor costs than would ordinarily be necessary. Also, because of the unusual reproduction to be released from shade, more work was done than would commonly be required. Ordinarily the better red maples, black gums, and hickories might have been saved to advantage for later demands. If this had been done, the cost would probably have been reduced to less than $1 an acre.

Girdling, of course, leaves the area in an unsightly condition for many years, and for this reason, where appearances are to be regarded, as along roads and trails, it may be preferable to fell the trees. Girdling, however, avoids the breakage of young trees and reproduction that would be almost inevitable if the trees were cut. Standing dead trees lose their branches and tops gradually through decay and when they fall they are not likely to cause much damage. They are not a very serious fire menace in this region.

WEEDING

On areas densely covered with rhododendrons, laurel, dogwood, sourwood, sassafras, and other shrubs or small trees, reproduction of desirable species has small chance of success. The cost of removing entirely a heavy cover of this kind would commonly be prohibitive, except by burning, which is dangerous. But a light partial cutting of the underbrush to release individual seedlings from shade can be made with relatively little expense. An example of such release cutting, to free good reproduction of yellow poplar, is given on pages 45 and 46. The cost of such operations will naturally vary with the quantity of reproduction that is to be released, the size and kind of brush, and other conditions. Working in fairly dense brush and confining his

efforts to the release of only a part of the best seedlings (say, 100 per acre), a good axman should be able to cover an acre a day. The freeing of some of the best reproduction from shade and competition is particularly important where good reproduction is scanty. Release cutting, however, is not universally necessary, and good reproduction may often be obtained without recourse to it.

THINNING

Wherever a market for small material can be found that will pay for the cost, dense young stands should be thinned at intervals to increase the quality and growth rate of the trees left. Thinnings should be directed toward favoring the growth of the most promising trees and best species. The smaller trees and particularly the defectives and the less desirable species should be removed. Thinnings are most effective if begun early in the life of the stand and repeated at 5 or 10 year intervals, or whenever the crowns of the trees left have closed up the openings made by the previous thinning. The thinning should leave the crown cover of the woods as evenly opened up as possible, with only such space around the crowns of the better trees as can be filled by their growth during the following 5 or 10 years. Larger openings can not, of course, be avoided where widespreading, defective trees are removed. Such openings will later be filled partly by the crowns of adjacent trees and partly by reproduction.

The kind and quantity of material to be removed in thinning depend on local differences in the composition, age, and density of the stands and hence are widely variable. Examples of one kind of thinning, which removed the smaller trees and left the larger ones standing, are described in a publication previously cited (*28*). Another type of thinning—one of three kinds applied experimentally by the Appalachian Forest Experiment Station in a dense 40-year-old stand of second-growth yellow poplar at Cranberry, N. C.—is illustrated in Figures 10 and 11. Here the larger trees were removed with the expectation that the thinning would increase the growth rate of the smaller trees left. Seventeen "long cords" (of 160 cubic feet) were removed per acre, and the stand after cutting contained 24 long cords per acre. The trees removed in thinning were sold as pulpwood.

Detailed discussions of the principles of thinning will be found in the standard textbooks on forestry.

SLASH DISPOSAL

The disposal of logging slash to favor reproduction or reduce fire hazard is not so much of a problem in the southern Appalachian region as it is in some other parts of the country. Where the accumulations are heavy, however, it is best to lop and scatter the branches that are 4 or 5 inches or more in diameter so that they will be close to the ground and decay rapidly. Care should be taken not to break or smother good reproduction under slash.

SPRUCE-FOREST MANAGEMENT FOR FULL CROPS

That partial cutting is practicable in the spruce forest and that it will be effective in perpetuating the stand is indicated by actual results from partial cuttings in West Virginia. Stands have been

culled or cut over twice for the larger trees, leaving an on-coming stand of small trees and reproduction. A study of the southern Appalachian spruce forest as affected by logging and fire, made by

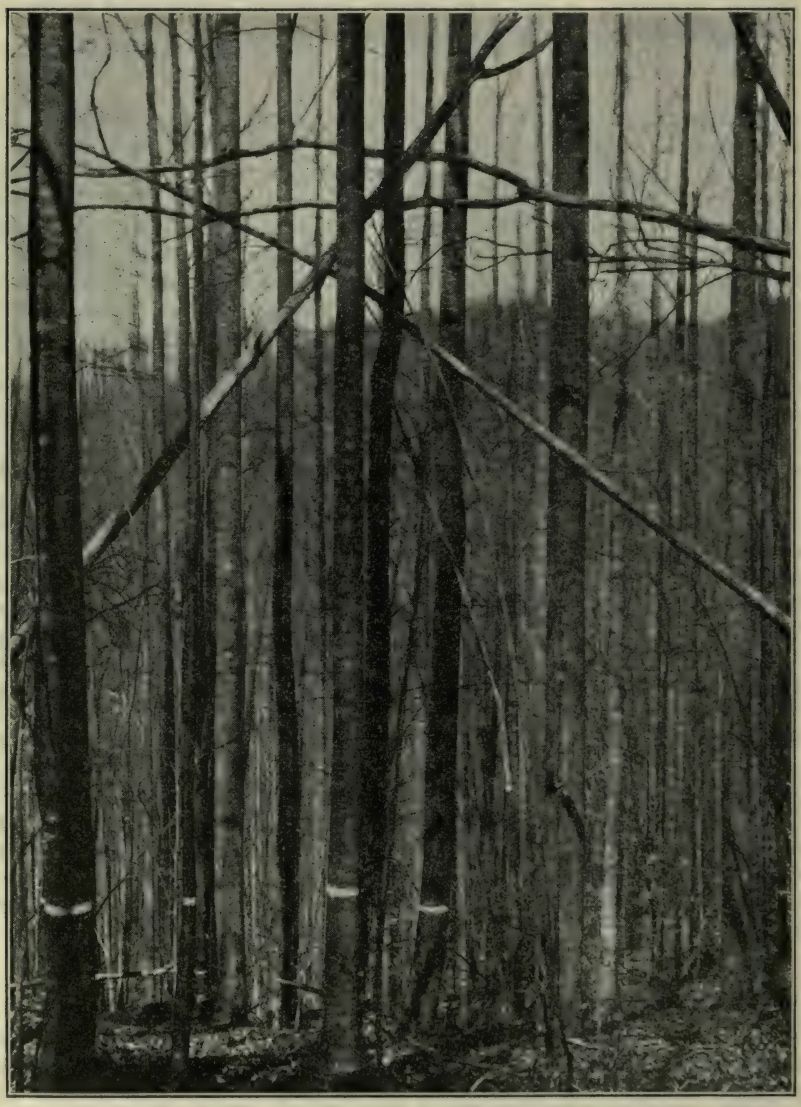

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FIGURE 10.—A selection thinning in a 40-year-old stand of second-growth yellow poplar that came in after clean cutting for charcoal wood. Dominant trees 95 feet in height indicate Site I. Before thinning the stand contained 41 long cords (ca. 160 cubic feet) per acre. (Cranberry, N. C.)

C. F. Korstian, for the Appalachian Forest Experiment Station, yielded evidence that partial cutting, coupled with effective fire prevention, is much the best means of making the spruce forest continuously productive.

This conclusion is confirmed by observations of the capacity of spruce and fir to establish reproduction in open or lightly shaded spots in the forest (pl. 12), the scarcity of the seedlings on clean-cut areas, especially after fire, and the small chance they have of growing

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FIGURE 11.—After thinning: The trees banded in Figure 10 have been released from competition; the stand still contains 24 long cords to the acre; in smaller trees, 17 cords having been removed and sold for pulpwood

up through the dense growth of hardwoods that customarily springs up on such areas. Partial cutting is further justified by the reduced fire menace when the forest floor is kept moist by partial shade and when the slash produced in logging is only from scattered trees

rather than from the whole stand. In the partial cutting the larger trees should be removed singly or in small groups, admitting some light through the crown cover but not opening the forest enough to cause windfall or the rapid invasion of hardwoods. Broken, diseased, insect-infested, and poorly formed trees should be removed. The time for a second cutting will depend upon the size and number of trees left in the stand and the rate at which the small openings in the crown cover close up. In most cases a return will be possible in 15 to 25 years. By such partial cuttings the stand will be kept in an active, producing condition.

Since the bulk of the wood volume of the stand may be contained in relatively few large trees, a cutting that removes only 20 per cent of the crown cover of the stand may take a much larger percentage of the total volume. Thus a paying yield may be obtained without greatly opening up the forest. Scattered merchantable hardwoods should be removed at the first cut, but where they are abundant so that their removal will seriously expose spruce and fir trees to wind throw, some should be left until a later cutting.

On cut-over and burned spruce land a satisfactory new stand of spruce, fir, or other softwoods can rarely be obtained except by planting. Planting should follow immediately after the burning to keep down the cost of the planting and to avoid the competition with raspberry, blackberry, and other bushy vegetation that will soon appear. Even when a burned area is planted promptly after fire, it will frequently be necessary later to cut back the natural reproduction of hardwoods, especially on the better soils.

Experiments to determine the species most suitable for planting on cut-over and burned spruce lands have been conducted since 1923 by the Appalachian Forest Experiment Station at high altitudes in the Black Mountains of North Carolina. In addition to the native red spruce and southern balsam fir, 15 introduced conifers were tested. The results for red spruce and southern balsam fir, as summarized from the spruce study above cited, are of interest. Southern balsam fir has given the best evidence of success, with a survival of from 82 to 85 per cent of the seedlings set out five years ago. The survivors averaged from 1.5 to 1.8 feet tall in 1929 and are growing vigorously. In three separate plantings of red spruce from 60 to 85 per cent survived and the trees averaged about the same height as the fir. The growth of spruce and fir during the first few years is always slow, and from now on a considerably more rapid height growth may be expected. Of the 15 introduced species, some have already failed and none has as yet demonstrated its superiority to the native spruce and fir for reforesting the devastated spruce lands. The best planting stock to use is evidently red spruce and southern balsam fir, preferably grown locally from locally collected seed. This stock should consist of thrifty transplants, grown two years in the seed bed and one or two years in transplant rows.

MANAGEMENT OF FARM WOODS

Farm woods are neglected opportunities on thousands of farms in the southern Appalachian region. Instead of being handled for a steady income, as they might easily be, a common practice has been to cull out the best material whenever it could be sold or used.

This has resulted in such poor stands that many owners have lost interest in their woods as a source of income. Lack of familiarity with markets and prices for wood products has placed farmers at a disadvantage, and much timber has been sacrificed for low-paying uses when some of it, at least, might far better have been left for growth to more valuable sizes. The aggregate loss through poor management of farm woods is serious to the region as a whole. The area of farm woods is so large (49 per cent of the total area of timberland) that if all were under good management for continuous production the united crop would go far toward meeting the wood requirements of the region.

Farm woods offer opportunities for treatment that are not possessed by the large tracts of timberland. They are in small units which can be easily managed in the course of other work on the farm. Labor and teams can be used in them during slack periods for other farm activities. There is no heavy investment in land, stumpage, and special equipment. Fuel and other wood products needed on the farm itself can be supplied from unmerchantable trees cut to benefit the stand. In the plateau and valley region the farm woods are usually accessible by good roads and by rail to sawmills, pulp and paper factories, and other establishments that require constant supplies of forest products. Such markets are an incentive for the management of farm woods to supply continuous yields of the most profitable materials. For these reasons it is relatively easy and practical for farmers to apply the intensive methods that lead to full timber crops.

The treatment that should be given farm woods to enable them to earn a steady income depends upon their condition, age, and composition. Conditions vary all the way from thin, overgrazed, or overburned stands in which the trees left are of no value except for fuel, to dense stands of thrifty timber. Some farm woods contain only mature trees; others are made up of young reproduction that came in when a previous stand was cut clean or a field was abandoned for cultivation. Many stands are of young second-growth pines or hardwoods, and some are of mixed ages, often with a young growth of hardwoods under an older stand of second-growth pine. Each stand, therefore, presents a problem that must be worked out independently, with a view to developing the most valuable and rapidly growing species and maintaining the largest and most profitable yield. Poor, thin stands can not be converted rapidly into good ones. The process is a slow one, and sometimes it is best to clear the ground and start a new stand by planting. Dense stands can, however, be improved by light partial cuttings in old growth or thinnings in second growth at intervals of 3 to 10 years.

The treatment of farm woods and the marketing of farm forest products are discussed in several Federal bulletins (*37*, *38*, *39*, *40*, *62*) and also in a number of State publications.

OLD-GROWTH STANDS

In most old-growth farm woods partial cuttings, as previously described, will be practical. The purpose of the first cuttings will be to get rid of the poorer trees. Trees with widespreading crowns should be removed, since they will otherwise retard the growth of

reproduction beneath them. Especially good trees of desirable species should be left for increased growth. A good procedure, after the preliminary improvement cutting, is to divide the farm woods into small blocks, to be cut over in successive years. In a 50-acre woods, if 5 acres are lightly cut over each year, 11 years will have gone by before the first block is revisited, and by that time another light cutting on the first block may have become desirable. Overcutting should not be permitted, and plenty of time should be allowed for each block to recover before any further cutting is done in it. The first cuttings should be in groups, so far as possible, and the reproduction which comes in on the small areas so cleared should be improved by weeding out the undesirable kinds. The subsequent cuttings may be aimed to increase the size of the openings and so of the reproducing areas. Thus eventually the woods will be restocked with young trees of different ages, and the process of cutting may be repeated indefinitely.

SECOND-GROWTH STANDS

In dense second-growth stands thinnings should be made, as previously described. The early thinnings, while giving the best trees space to grow rapidly, should not be heavy enough to permit the trees left to develop widespreading crowns. It is best to thin lightly and often. A good rule is to thin when possible so as to leave a space of not more than 3 to 5 feet between the crowns. A space of this size will probably be filled in as many years by the spread of the branches, and the thinning should then be repeated. The thinnings should be started as early as possible in the life of the stands. The trees removed, even when small, will often help to pay for the operation in the form of fuel, bean poles, grape stakes, etc. Early thinnings should, of course, remove inferior species and crooked or defective trees. As a result of a well-executed sequence of thinnings, the stand will ultimately contain only sound, straight trees of the best species, with long boles and compact crowns. Besides giving intermediate yields of small-sized material for use on the farm or for sale, consecutive thinnings, properly made, concentrate the growth of the area upon a relatively small number of trees which are thus brought to saw-log size more quickly than if nature were unaided.

SPECIES TO BE FAVORED

In partial cuttings and thinnings the species to be favored of those present in the stand can best be the species that are well adapted to the condition of the soil. A key to the relative desirability of species adapted to moist and to dry soils is given in Table 2. In the farm woods of the plateaus and of the great Appalachian Valley the dry-soil species that it will be well to favor, where they occur, are shortleaf pine and southern red, black, chestnut, and white oaks. In moister situations a great variety of species is to be found, the more desirable of which are shortleaf and white pines, black walnut, yellow poplar, white ash, black cherry, black locust, basswood, white oak, red oak, southern red oak, and mockernut and shagbark hickories. In still moister places, as along stream beds, red gum, yellow poplar, white ash, and several species of oak should

be favored. These species are mostly intolerant of shade, and their reproduction requires plenty of light.

Where shortleaf pine occurs it is one of the very best species to favor. Loblolly pine is even better, though its occurrence is limited in the region under discussion to the eastern and southern edges of the piedmont plateau and the southern part of the Tennessee Valley. These and Virginia pine (scrub pine) commonly grow in dense, even-aged old-field stands which are subject to management by thinnings and a final clear cutting when the trees reach large size, a few trees being left standing to seed up the cut-over area.

CONTROL OF GRAZING

Grazing rarely causes serious injury in the large unfenced timber tracts in the mountains, but in fenced farm woods it often results in complete destruction of the reproduction. What is not eaten is broken, stripped of bark, or bent over and trampled. The trampling compacts the soil, rendering it unreceptive to tree seedlings and unfavorable for good growth of larger trees. Many of the larger trees die in the tops as the result of trampling. Gradually the pastured farm woods become thin and unhealthy as the trees continue to die off. Hope of improvement is lacking so long as the cattle are allowed to remain.

Livestock should be excluded from farm woods that are in process of reproduction, at least until the new crop of seedlings or sprouts has grown beyond danger of injury. In thinly wooded tracts that have been heavily overgrazed this may mean a period of 15 or 20 years. Closing the woods to grazing involves little loss, since investigators have found that grass grown under tree shade is poorer in sugars and other carbohydrates, and therefore less nutritious, than if grown in the open (*73*). The density of grass produced in the woods is also much less than in the open. The tree shade desired for cattle should be provided by fencing off a small part of the woods expressly for that purpose.

COOPERATIVE MARKETING

Although in every other respect the individual owner of farm woods may successfully apply the principles of efficient forest management in the production of a continuous supply of high-grade forest products, he is likely to fall seriously short of reaping a just return when he attempts to market his products single handed. He sometimes has as many as three middlemen between himself and the manufacturer, each of whom will draw a profit. If the price offered by the manufacturer is $8 a cord f. o. b., the farmer may receive only $5 a cord for his cut products in the woods. Direct dealing with the manufacturer is obviously preferable, but since an individual farmer may have only a small amount of wood to dispose of this is not always possible. In any case, a still better arrangement will be for all or a number of farmers living near each other to combine to organize their sales on the basis of competitive bids and for quantity shipment.

Where a farmers' federation or similar organization already exists, it is a comparatively simple matter to include in its activities

the systematic marketing of farm-forest products. An illustration can be cited in the case of the Farmers' Federation of Western North Carolina, which in 1930 organized a bureau for the sale of material from the farm woods. The federation employs a woods agent, whose duty is to obtain favorable contract agreements with purchasers of a variety of woods products, which are assembled from numerous farms and shipped by the carload. Cash is paid for products presented at the federation's warehouses located at strategic points in the region served. Profits, above a small percentage for operating expenses, are shared. Although this marketing agency is very young, several markets hitherto unused by farmers have already been developed. Shipments have already been made of ornamental shrubbery, chemical distillation wood, black locust posts and insulation-pin stock, red oak ties for treatment, dogwood for shuttle blocks, and veneer logs of several species. The collection and shipping of these products is now proceeding regularly. In addition, several new uses for blight-killed chestnut are being worked out to supplement the present uses as poles and tanning-extract wood. The federation is going into the development of new markets intensively and is making every effort to bring the farm woods of the region to their rightful place as sources of revenue (*43*).

An objection sometimes made to cooperative marketing of farm-forest products is based upon the belief that such products can be produced on any one farm only at long intervals and in small quantities. This belief is justified for poor, pastured woods but not for woods in a good producing condition. Well-managed cooperative marketing and a well-managed wood lot will make it possible for a farmer to market wood products at frequent intervals, no matter how small the amount, and will assure the best prices. Best of all, it will organize the disposal of these materials on a permanent basis so that a farmer can look forward to a steady income from his woods and can plan well in advance a paying program of improvement.

SUMMARY OF RECOMMENDATIONS FOR HANDLING FOREST LANDS

TO KEEP FOREST LANDS PRODUCTIVE

FIRE PREVENTION

Cooperative fire protective forces, maintained by county, State, and Federal Governments, to be supplemented by timberland owners, individually or through associations.

Cooperative patrol and lookout systems to be maintained, with special vigilance during fire seasons; patrol to be concentrated upon areas of special hazard.

Local fire-fighting forces to be recruited and kept in readiness under appointed wardens.

Slash disposal only on protective strips adjacent to railroads, highways, sawmills, etc.

Protective equipment to be required on locomotives, sawmills, etc., in forested country.

Advance notification to occupants of adjoining lands and to local firewardens when fires are set to burn brush or for other purposes.

Responsibility for escape of fires to be ensured by legal measures. All means to be used to inform and educate local residents, campers, tourists, and other users of the forest as to the risks and losses from fire.

INSECT CONTROL[12]

The adoption of measures for the prevention or control of forest insects as well as forest fires will aid further in putting timberlands into a condition for continuous timber production.

MEASURES AGAINST INSECTS IN LIVING TREES

Briefly, an important step in the protection of pine against attacks of the southern pine beetle consists in encouraging the development of mixed stands of pine and hardwoods. Such stands not only are less susceptible to further bark-beetle outbreaks but also will produce a better grade of softwood lumber. Summer cutting of pines should be avoided whenever possible. Fires in pine areas increase the danger from pine-beetle attack and also destroy the hardwoods within the area, thus tending to create pure pine stands, which are always subject to attack.

The prevention of injury by the chestnut timber worm, the oak timber worm, and the Columbian timber beetle is rather difficult. As they infest mature, overmature, or young trees, which have been injured mechanically by the breaking off of limbs or by such agencies as fire, lightning, or frost, which break or scar the bark, the only measure that can be adopted is to encourage the removal of heavily infested brood trees during cutting operations, when such a procedure is practical, since such trees serve as a source of infestation to the timber in the surrounding forest.

Locust-borer attack can be largely eliminated by silvicultural practices. Studies (*15*) made on the habits of this insect have shown that shade is an important factor in protecting young growth. Locusts that are protected by shade through close, mixed plantings until the trees have attained a diameter of about 6 inches are not subject to extensive injury by this insect. A thick growth of trees in nature appears to sustain very little injury. This also aids in producing straight, unbranched boles. If such protected stands are thinned too soon, insects are attracted and the trees injured. Very little injury will result from pruning and thinning after the bole of the tree has reached a diameter of 6 inches.

Injury caused by the hickory bark beetle to weakened trees can not be prevented except by adopting such practices of forest management as will keep the trees in a sound and vigorous condition.

MEASURES AGAINST INSECTS AFFECTING FOREST PRODUCTS

In general, pinhole and wormhole defects in green logs and lumber can be eliminated by handling the product so that it will be in a condition unfavorable for attack by insects. Often this can be ac-

[12] Prepared by R. A. St. George Associate Entomologist Division of Forest Insects, Bureau of Entomology. For further information the following should be consulted: (*15, 49, 51, 53, 54, 55*).

complished by adopting changed practices in forest management which differ only slightly from those in use in the regular operations. The following procedure is suggested to eliminate or minimize this injury:

Allow as little delay as possible between the felling of the tree and its manufacture into rough products, especially during the active season.

Round timber that must be left in the woods during the period of danger should be placed on skids or precautions taken otherwise to facilitate the rapid drying of the inner bark, or else the opposite extreme should be adopted and the logs completed immersed in water.

The removal of bark from all poles, posts, and other materials which will not be seriously damaged by checking, should be undertaken.

The bark should be removed from the edges of lumber, especially heavy dimension stock. Kiln-drying or end-racking of certain kinds of lumber will aid in preventing injury by most insects.

Damage by powder-post beetles to seasoned lumber and unfinished and manufactured wood products can be largely prevented by periodical inspection and proper classification, piling, and handling of stock.

Damage by insects to tanbark will be slight if the latter is utilized within two to three years after its removal from the tree.

LOGGING PRACTICE

HARDWOODS, HEMLOCK, AND PINE

Mature timber to be cut, using every means to market all defective and unpromising trees.

Promising small trees to be reserved in groups, what trees are large enough to be logged at a profit being determined before cutting.

Isolated trees and trees broken in logging to be cut to as small diameters as can be utilized, so as to leave open spaces for reproduction.

On areas of an acre or larger that would be cleared under above practice, good seed trees of desirable species to be left.

Subsequent logging to be postponed until stand is again in condition to support a paying operation and still leave a nucleus of young trees and reproduction for future cutting.

Cuttings to be lighter and less frequent on dry sites than on moist.

SPRUCE FOREST

If it is desired to perpetuate the softwood stand, a light to moderate selective logging is recommended, removing other species along with the larger spruce trees and leaving small spruce for later cuttings.

Cut-over spruce lands to be left under fire protection for growth of a new stand.

TO PRODUCE FULL TIMBER CROPS

LARGE TIMBER TRACTS

Thorough protection from fire, as outlined under measures to keep forest lands productive.

Systematic development of the tract by means of a definite schedule of cuttings so planned that a reserve of immature timber of different ages will be built up and maintained. These may be either clean cuttings, designed to develop the growing stock entirely from reproduction, or partial (selective) cuttings to permit immature trees as well as reproduction to form the basis of the new crop. The latter method is especially desirable in mixed forests in which different species become merchantable at different ages and sizes.

In stands managed by partial cuttings, trees to be removed singly, or in groups where clumps of good reproduction are already present.

Machine logging not to be used in partial cutting.

Unmerchantable large trees and unpromising small ones to be cut or girdled. The cost of this should ordinarily be less than $1 an acre.

Where desirable young growth is shaded or crowded by dense underbrush or less desirable tree species, some of the desirable saplings should be freed by light release cuttings. This should cost, on the average, about $2.50 an acre, but will rarely be necessary over an extended area.

Second-growth stands to be improved by thinning and weeding.

SPRUCE FOREST

Cutting to be generally by individual scattered trees or very small groups, comprising the removal of broken, diseased, insect-infested, and poorly formed trees.

On cut-over and burned spruce lands planting is usually the only way to insure a satisfactory new stand of softwoods; even if done promptly after the fire it will frequently be necessary to assist the planted seedlings by cutting back hardwoods that seed in.

FARM WOODS

Series of light partial cuttings at intervals are generally the best treatment for well-stocked old-growth woods, removing the poorer and widespreading trees in the first cuttings. Trees to be removed in small groups so far as possible, the size of the openings thus made to be gradually increased in later cuttings.

Dense second-growth stands to be thinned lightly at intervals, which may be as frequent as five years, depending upon rate at which the openings close up.

In thinnings and partial cuttings, the least valuable species to be removed, favoring those of value that seem best adapted to the soil conditions.

For thin, overgrazed woods, planting.

Livestock to be excluded from farm woods that are reproducing.

Systematic operation by dividing the woods into blocks to be cut over serially, even in small farm woods.

Cooperative marketing by farmers as a means for joint sale, to highest bidders, of small individual quantities of wood products.

PUBLIC ACTION NEEDED FOR BETTER DEVELOPMENT OF TIMBERLANDS

The strong interest of the public in good forest management carries an obligation for the enactment of public measures to protect and stimulate timber and game production. As previously shown, 95 per cent of the southern Appalachian forest and woodland is privately owned. To encourage the economic development of this land, public policies covering the major phases of forest protection, taxation, education, demonstration, and research should be made effective. All means should be taken to bring about the best use of the greatest possible area of timberland, and thus to increase its productivity as a source of supply for local needs as well as for export to other parts of the country. Programs to accomplish this should include the following important items:

Substantial increases in State and Federal funds for forest-fire prevention and suppression. This is the most necessary of all action to improve forests for continuous production. Special effort should be directed toward getting all counties to participate by voting cooperative funds. The resources of the State foresters for combating fires should be increased. Cooperative protective organizations of timberland owners should be encouraged.

A fire-weather warning service for the southern Appalachian region. Studies (*42*) indicate that such a service would be entirely feasible in this region, as it is proving in others. It would permit concentration of man power at times of special danger and thus work for economy and efficiency of the protective forces.

State or cooperative investigations of forest resources to determine (1) the location and extent of land particularly fitted for timber growing and (2) the quantity of merchantable timber and immature timber adapted to the different classes of industrial use. Provisions for Federal participation in such investigations are contained in the McSweeney-McNary Act.

Acquisition of well-located public forests. In order to insure good distribution of an adequate area of public forests, as well as to serve all public interests to best advantage, definite programs for forestland acquisition should be conducted by both the State and the Federal Governments. The advantage, also, of county and town forests has been demonstrated abroad and even at some points in the United States. In the southern Appalachian region there are already nearly 62,000 acres of county or municipally owned forests and parks (*72*). Much of this is held for watershed protection. For the combined advantages of timber production, game protection, education, and recreation, cities can well afford to purchase and develop near-by tracts of woodland or of worn-out farm land suitable for planting.

Encouragement of investigations of the rate of growth of forests, their reproduction and management, and the improvement of protective measures.

Studies of the conditions that determine the influence of forests upon erosion and stream flow, with particular reference to the silting up of stream channels and reservoirs and the regularity of the flow.

Provision for research into better utilization of forest products, with a view to extending the markets for small trees and inferior

species and thus reducing materially the cost of cleanings, weeding, and thinning.

Investigations to determine the best methods of maintaining and protecting game in the forest, as a part of efficient forest management.

Educational programs to develop popular appreciation of the values of forests. Fire prevention should be emphasized as the basic requirement for forest production. Educational activities should be directed to all users of the forest through the press, schools, and other agencies.

Increased demonstrations of good forest practice in farm woodlands, through State forestry extension services. Actual examples of good forest management in each county will serve more than anything else to spread an understanding of its methods and advantages.

Encouragement of cooperative marketing by farmers as a means of developing sustained-yield management of farm woods.

Adoption of State laws providing forms of forest taxation that will protect growing timber from a burdensome application of the general property tax.

APPENDIX

SOURCES OF TECHNICAL ADVICE AND SERVICE FOR PRIVATE FOREST MANAGEMENT

The organization of forest lands for management, the preparation of plans, and the execution of these plans call for the special knowledge and experience possessed by technically trained foresters. There are numerous sources, in the southern Appalachian States, from which information and advice can be obtained. First among these are the State forestry offices at Baltimore, Md., Charlottesville, Va., Raleigh, N. C., Columbia, S. C., Charleston, W. Va., Frankfort, Ky., Nashville, Tenn., Atlanta, Ga., and Montgomery, Ala. The State foresters and their district foresters stationed at other towns and cities are prepared to give advice as to the best handling of forest tracts and to cooperate in their protection. In several of the States stock for forest planting is now being raised in State cooperative nurseries and can be obtained at cost by State residents upon application to the State forester.

Examinations of tracts for management, valuation of forest lands, and the preparation of plans for management can best be put in the hands of competent consulting foresters. Where permanent residence of a forester on the tract is not required—as it may not be during the preliminary period of management—consulting foresters may be engaged to supervise all management activities provided in the working plan.

For farm woods, a cooperative forestry extension service is maintained in most of the States, and advice on management and the marketing of forest products can readily be obtained. The farm extension forester is usually located at the State agricultural experiment station.

COMMON AND SCIENTIFIC NAMES OF TREES REFERRED TO IN TEXT

The following list includes the more common tree species of the region. Trees which commonly do not reach saw-log size are designated by an asterisk. The nomenclature is that used by Sudworth (*61*).

Common name	Scientific name
Ash	*Fraxinus* sp.
Basswood	*Tilia* sp.
Beech	*Fagus grandifolia*
*Beech, blue	*Carpinus caroliniana*
Birch, river	*Betula nigra*
Birch, sweet	*Betula lenta*

Common name	Scientific name
Birch, yellow	*Betula lutea*
Buckeye, Ohio	*Aesculus glabra*
Buckeye, yellow	*Aesculus octandra*
Butternut	*Juglans cinerea*
Cedar, eastern red	*Juniperus virginiana*
Cherry, black	*Prunus serotina*
*Cherry, pin	*Prunus pennsylvanica*
Chestnut	*Castanea dentata*
*Chinquapin	*Castanea pumila*
Coffeetree	*Gymnocladus dioicus*
*Crab apple	*Malus* sp.
*Dogwood	*Cornus florida*
Elm, American	*Ulmus americana*
Elm, slippery	*Ulmus fulva*
Elm, winged	*Ulmus alata*
Fir, southern balsam	*Abies fraseri*
Gum, black	*Nyssa sylvatica*
Gum, red	*Liquidambar styraciflua*
Hackberry	*Celtis occidentalis*
*Hawthorn	*Crataegus* sp.
Hemlock, Carolina	*Tsuga caroliniana*
Hemlock, eastern	*Tsuga canadensis*
Hickory	*Hicoria ovalis*
Hickory, bitternut	*Hicoria cordiformis*
Hickory, mockernut	*Hicoria alba*
Hickory, pignut	*Hicoria glabra*
*Hickory, pignut	*Hicoria pallida*
Hickory, shagbark	*Hicoria ovata*
Hickory, bigleaf shagbark	*Hicoria laciniosa*
Hickory, southern shagbark	*Hicoria carolinae-septentrionalis*
*Holly	*Ilex opaca*
*Hophornbeam	*Ostrya virginiana*
Locust, black	*Robinia pseudoacacia*
Locust, honey	*Gleditsia triacanthos*
Magnolia, cucumber	*Magnolia acuminata*
*Magnolia, mountain	*Magnolia fraseri*
*Magnolia, umbrella	*Magnolia tripetala*
Maple, black	*Acer nigrum*
Maple, red	*Acer rubrum*
Maple, silver	*Acer saccharinum*
Maple, sugar	*Acer saccharum*
*Mountain-ash	*Sorbus americana*
*Mulberry, red	*Morus rubra*
Oak, black	*Quercus velutina*
*Oak, blackjack	*Quercus marilandica*
Oak, chestnut	*Quercus montana*
Oak, chinquapin	*Quercus muehlenbergii*
Oak, pin	*Quercus palustris*
Oak, post	*Quercus stellata*
Oak, red	*Quercus borealis*
Oak, southern red	*Quercus rubra*
Oak, scarlet	*Quercus coccinea*
Oak, shingle	*Quercus imbricaria*
Oak, swamp white	*Quercus bicolor*
Oak, water	*Quercur nigra*
Oak, white	*Quercus alba*
Pine, mountain	*Pinus pungens*
Pine, northern white	*Pinus strobus*
Pine, pitch	*Pinus rigida*
Pine, shortleaf	*Pinus echinata*
Pine, Virginia	*Pinus virginiana*
Persimmon	*Diospyros virginiana*
Poplar, yellow	*Liriodendron tulipifera*
*Redbud	*Cercis canadensis*
*Rhododendron, great	*Rhododendron maximum*
*Sassafras	*Sassafras variifolium*

Common name	Scientific name
*Serviceberry	*Amelanchier canadensis*
*Silverbell	*Halesia carolina*
Silverbell, mountain	*Halesia monticola*
*Sourwood	*Oxydendrum arboreum*
Spruce, red	*Picea rubra*
Sycamore	*Platanus occidentalis*
Walnut, black	*Juglans nigra*
*Willow, black	*Salix nigra*

LITERATURE CITED

(1) ASHE, W. W.
1908. TERRACING OF FARM LANDS. N. C. Geol. and Econ. Survey Bul. 17, 38 p., illus.

(2) ———
1913. SHORTLEAF PINE IN VIRGINIA; THE INCREASE IN ITS YIELD BY THINNING. 44 p., illus. Richmond. (Va. Dept. Agr. and Immigr. in cooperation with U. S. Dept. Agr., Forest Service.)

(3) ———
1913. YELLOW POPLAR IN TENNESSEE. Tenn. Geol. Survey Bul. 10–C, 56 p., illus.

(4) ———
1926. FINANCIAL LIMITATION IN THE EMPLOYMENT OF FOREST COVER IN PROTECTING RESERVOIRS. U. S. Dept. Agr. Bul. 1430, 35 p., illus.

(5) ———
1927. RELATION OF SIZE OF TREE TO LOGGING COSTS, STUMPAGE VALUES, AND PROFITS. South. Lumberman 125 (1620) : 31–32.

(6) ———
1930. SMALL TREES WASTEFUL TO CUT FOR SAW TIMBER. U. S. Dept. Agr. Leaflet 55, 5 p., illus.

(7) BAKER, F. S.
1921. BLACK WALNUT: ITS GROWTH AND MANAGEMENT. U. S. Dept. Agr. Bul. 933, 43 p., illus.

(8) BENNETT, H. H., and CHAPLINE, W. R.
1928. SOIL EROSION A NATIONAL MENACE. U. S. Dept. Agr. Circ. 33, 36 p., illus.

(9) BOISEN, A. T., and NEWLIN, J. A.
1910. THE COMMERCIAL HICKORIES. U. S. Dept. Agr., Forest Serv. Bul. 80, 64 p., illus.

(10) BRUNER, E. M.
1928. PROGRESS IN FOREST PROTECTION IN THE SOUTH. Jour. Forestry 26: 299–314.

(11) BRUSH, W. D.
1921. UTILIZATION OF BLACK WALNUT. U. S. Dept. Agr. Bul. 909, 89 p., illus.

(12) ———
1922. UTILIZATION OF BASSWOOD. U. S. Dept. Agr. Bul. 1007, 64 p., illus.

(13) ———
1925. SELLING BLACK WALNUT TIMBER. U. S. Dept. Agr. Farmers' Bul. 1459, 21 p., illus.

(14) BUELL, J. H.
1928. WHAT CAN BE DONE WITH SOUTHERN APPALACHIAN CUT-OVER AREAS? South. Lumberman 133 (1734) : 211–212, illus.

(15) CRAIGHEAD, F. C.
1919. PROTECTION FROM THE LOCUST BORER. U. S. Dept. Agr. Bul. 787, 12 p., illus.

(16) ——— and ST. GEORGE, R. A.
1928. SOME EFFECTS OF FIRE AND INSECT ATTACK ON SHORTLEAF PINE. U. S. Dept. Agr., Forest Serv. Forest Worker 4 (2) : 11–12.

(17) CUNO, J. B.
1926. UTILIZATION OF DOGWOOD AND PERSIMMON. U. S. Dept. Agr. Bul. 1436, 43 p., illus.

(18) ———
1930. UTILIZATION OF BLACK LOCUST. U. S. Dept. Agr. Circ. 131, 20 p., illus.

(19) ELDREDGE, I. F.
1928. MANAGEMENT PLANS WITH SPECIAL REFERENCE TO THE NATIONAL FORESTS. U. S. Dept. Agr. Misc. Pub. 11, 84 p., illus.
(20) FOSTER, H. D., and ASHE, W. W.
1908. CHESTNUT OAK IN THE SOUTHERN APPALACHIANS. U. S. Dept Agr., Forest Serv. Circ. 135, 23 p.
(21) FROTHINGHAM, E. H.
1914. WHITE PINE UNDER FOREST MANAGEMENT. U. S. Dept. Agr. Bul. 13, 70 p., illus.
(22) ———
1915. THE EASTERN HEMLOCK. (TSUGA CANADENSIS (LINN.) CARR.) U. S. Dept. Agr. Bul. 152, 43 p., illus.
(23) ———
1924. SOME SILIVICULTURAL ASPECTS OF THE CHESTNUT BLIGHT SITUATION. Jour. Forestry 22: 861–872.
(24) ———
1925. THE PRESENT STAND OF CHESTNUT IN NORTH CAROLINA AND IN THE SOUTHERN APPALACHIANS. N. C. Geol. and Econ. Survey, Econ. Paper 56: [11]–12.
(25) GILL, L. S., and CLAPPER, R. B.
1928. THE PRESENT CHESTNUT PROBLEM IN THE SOUTH. South. Lumberman 131 (1701): 41–42, illus.
(25a) GRAVATT, G. F., and GILL, L. S.
1930. CHESTNUT BLIGHT. U. S. Dept. Agr. Farmers' Bul. 1641, 18 p., illus.
(26) ——— and MARSHALL, R. P.
1926. CHESTNUT BLIGHT IN THE SOUTHERN APPALACHIANS. U. S. Dept. Agr. Circ. 370, 11 p., illus.
(27) GREELEY, W. B., and ASHE, W. W.
1907. WHITE OAK IN THE SOUTHERN APPALACHIANS. U. S. Dept. Agr., Forest Serv. Circ. 105, 27 p.
(28) HAASIS, F. W.
1930. FOREST PLANTATIONS AT BILTMORE, N. C. U. S. Dept. Agr. Misc. Pub. 61, 30 p., illus.
(29) HALL, R. C.
1917. TIMBER ESTIMATING IN THE SOUTHERN APPALACHIANS. Jour. Forestry 15: 310–321.
(30) HODSON, E. R.
1920. IS AMERICAN CHESTNUT DEVELOPING IMMUNITY TO THE BLIGHT? Jour. Forestry 18: 693–700.
(31) HOPKINS, A. D.
1921. THE SOUTHERN PINE BEETLE: A MENACE TO THE PINE TIMBER OF THE SOUTHERN STATES. U. S. Dept. Agr. Farmers' Bul. 1188, 15 p., illus.
(32) HURSH, C. R.
1928. LITTER KEEPS FOREST SOIL PRODUCTIVE. South. Lumberman 133 (1734): 219–221, illus.
(33) KORSTIAN, C. F.
1924. THE TRAGEDY OF CHESTNUT. HOW AN UNCONTROLLABLE PEST IS EXTERMINATING A VALUABLE HARDWOOD SPECIES. South. Lumberman 117 (1525): 180–183, illus.
(34) ———
1927. FACTORS CONTROLLING GERMINATION AND EARLY SURVIVAL IN OAKS. Yale Univ. School Forestry Bul. 19, 115 p., illus.
(35) ——— and STICKEL, P. W.
1927. THE NATURAL REPLACEMENT OF BLIGHT-KILLED CHESTNUT. U. S. Dept. Agr. Misc. Circ. 100, 15 p., illus.
(36) ——— and STICKEL, P. W.
1927. THE NATURAL REPLACEMENT OF BLIGHT-KILLED CHESTNUT IN THE HARDWOOD FORESTS OF THE NORTHEAST. Jour. Agr. Research 34: 631–648, illus.
(37) MATTOON, W. R.
1920. FORESTRY AND FARM INCOME. U. S. Dept. Agr. Farmers' Bul. 1117, 35 p., illus.
(38) ———
1920. MAKING WOODLANDS PROFITABLE IN THE SOUTHERN STATES. U. S. Dept. Agr. Farmers' Bul. 1071, 30 p., illus. (Revised, 1926.)

(39) MATTOON, W. R.
1928. THE FARM WOODS—A SAVINGS BANK PAYING INTEREST. U. S. Dept. Agr. Leaflet 29, 7 p., illus.
(40) ——— and BARROWS, W. B.
1916. MEASURING AND MARKETING WOODLOT PRODUCTS. U. S. Dept. Agr. Farmers' Bul. 715, 48 p., illus.
(41) ——— and REED, C. A.
1924. BLACK WALNUT FOR TIMBER AND NUTS. U. S. Dept. Agr. Farmers' Bul. 1392, 30 p., illus.
(42) MCCARTHY, E. F.
1927. WEATHER AND FOREST INFLAMMABILITY IN THE SOUTHERN APPALACHIANS. U. S. Mo. Weather Rev. 55: 119–122, illus.
(43) MCCLURE, J. G. K., JR.
1930. FEDERATION WILL SELL FARMERS' FOREST PRODUCTS. Farmers' Fed. News 10: (January) Asheville, N. C.
(44) MURPHY, L. S.
1917. THE RED SPRUCE: ITS GROWTH AND MANAGEMENT. U. S. Dept. Agr. Bul. 544, 100 p., illus.
(45) NELSON, R. M., and GRAVATT, G. F.
1929. THE TANNIN CONTENT OF DEAD CHESTNUT TREES. Jour. Amer. Leather Chem. Assoc. 24: 479–499, illus.
(46) PAUL, B. H.
1930. THE APPLICATION OF SILVICULTURE IN CONTROLLING THE SPECIFIC GRAVITY OF WOOD. U. S. Dept. Agr. Tech. Bul. 168, 20 p., illus.
(47) PIERSON, A. H.
1910. CONSUMPTION OF FIREWOOD IN THE UNITED STATES. U. S. Dept. Agr., Forest Serv. Circ. 181, 7 p., illus.
(48) REED, F. W.
1929. SALVAGING THE CHESTNUT. Amer. Forests and Forest Life 35: 103–106, illus.
(49) ST. GEORGE, R. A.
1929. PROTECTION OF LOG CABINS, RUSTIC WORK, AND UNSEASONED WOOD FROM INJURIOUS INSECTS. U. S. Dept. Agr. Farmers' Bul. 1582, 20 p., illus.
(50) ———
1929. WEATHER, A FACTOR IN THE OUTBREAKS OF THE HICKORY BARK BEETLE. Jour. Econ. Ent. 22: 573–580, illus.
(51) ——— and BEAL, J. A.
1929. THE SOUTHERN PINE BEETLE: A SERIOUS ENEMY OF PINES IN THE SOUTH. U. S. Dept. Agr. Farmers' Bul. 1586, 18 p., illus.
(52) SHERMAN, E. A.
1928. THE PROTECTION FORESTS OF THE MISSISSIPPI RIVER WATERSHED AND THEIR PART IN FLOOD PREVENTION. U. S. Dept. Agr. Circ. 37, 50 p., illus.
(53) SNYDER, T. E.
1926. PREVENTING DAMAGE BY LYCTUS POWDER-POST BEETLES. U. S. Dept. Agr. Farmers' Bul. 1477, 13 p., illus.
(54) ———
1926. PREVENTING DAMAGE BY TERMITES OR WHITE ANTS. U. S. Dept. Agr. Farmers' Bul. 1472, 22 p., illus.
(55) ———
1927. DEFECTS IN TIMBER CAUSED BY INSECTS. U. S. Dept. Agr. Bul. 1490, 47 p., illus.
(56) SOCIETY OF AMERICAN FORESTERS, COMMITTEE OF THE SOUTHERN APPALACHIAN SECTION.
1926. A FOREST TYPE CLASSIFICATION FOR THE SOUTHERN APPALACHIAN MOUNTAINS AND THE ADJACENT PLATEAU AND COASTAL PLAIN REGIONS. Jour. Forestry 24: 673–684.
(57) SPAULDING, P.
1916. THE WHITE-PINE BLISTER RUST. U. S. Dept. Agr. Farmers' Bul. 742, 15 p., illus.
(58) STERRETT, W. D.
1911. SCRUB PINE. (PINUS VIRGINIANA.) U. S. Dept. Agr., Forest Serv. Bul. 94, 27 p.
(59) ———
1915. THE ASHES, THEIR CHARACTERISTICS AND MANAGEMENT. U. S. Dept. Agr. Bul. 299, 88 p., illus.

(60) STERRETT, W. D.
1917. UTILIZATION OF ASH. U. S. Dept. Agr. Bul. 523, 52 p., illus.
(61) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES: THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 295 p.
(62) TILLOTSON, C. R.
1920. THE CARE AND IMPROVEMENT OF THE FARM WOODS. U. S. Dept. Agr. Farmers' Bul. 1177, 27 p., illus.
(63) TOUMEY, J. W., and KORSTIAN, C. F.
1930. SEEDING AND PLANTING IN THE PRACTICE OF FORESTRY. Ed. 2. New York.
(64) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE.
1907. BASSWOOD. U. S. Dept. Agr., Forest Serv. Circ. 63, 3 p.
(65) ———
1907. BLACK CHERRY (PRUNUS SEROTINA). U. S. Dept. Agr., Forest Serv. Circ. 94, 3 p.
(66) ———
1907. BLACK LOCUST (ROBINIA PSEUDOACACIA). U. S. Dept. Agr., Forest Serv. Circ. 64, 4 p.
(67) ———
1907. RED OAK (QUERCUS RUBRA). U. S. Dept. Agr., Forest Serv. Circ. 58, 3 p.
(68) ———
1907. SHAGBARK HICKORY (HICORIA OVATA). U. S. Dept. Agr., Forest Serv. Circ. 62, 3 p.
(69) ———
1907. WHITE ASH (FRAXINUS AMERICANA). U. S. Dept. Agr., Forest Serv. Circ. 84, 4 p.
(70) ———
1907. BLACK WALNUT (JUGLANS NIGRA). U. S. Dept. Agr., Forest Serv. Circ. 88, 5 p.
(71) ———
1920. TIMBER DEPLETION, LUMBER PRICES, LUMBER EXPORTS, AND CONCENTRATION OF TIMBER OWNERSHIP. Report on Senate Resolution 311, 71 p., illus. Washington, D. C.
(72) ———
1928. AMERICAN FORESTS AND FOREST PRODUCTS. U. S. Dept. Agr. Statis. Bul. 21, 324 p., illus.
(73) WELTON, F. A., and MORRIS, V. H.
1928. WOODLAND PASTURE. Jour. Forestry 26: 794–796.
(74) ZON, R.
1907. MANAGEMENT OF SECOND-GROWTH IN THE SOUTHERN APPALACHIANS. U. S. Dept. Agr., Forest Serv. Circ. 118, 22 p.
(75) ———
1927. FORESTS AND WATER IN THE LIGHT OF SCIENTIFIC INVESTIGATIONS. (Reprinted from Appendix V, Final Report of United States National Waterways Commission, U. S. Congress 62d, Sess. 2, Senate Doc. 469.) 106 p., illus.

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